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Phillips

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(54) **ANKLE BLOCK WITH SPRING INSERTS**

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(52) **U.S. Cl.** **623/53**; 623/55; 623/47; 623/49

(58) **Field of Search** 623/47–55

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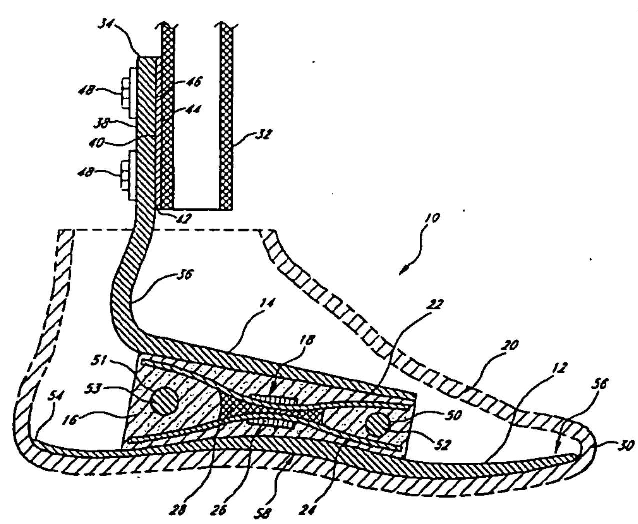
(57) **ABSTRACT**

Provided herein is a simple, inexpensive prosthetic foot incorporating an ankle block with spring inserts. The ankle block is formed of compressible material having desired compliance and energy return characteristics. The ankle block is sandwiched between a foot element and an ankle element. One or more spring inserts are embedded inside the ankle block to increase the rigidity of the prosthetic foot and to improve the degree of energy storage and return. The shape of the spring inserts is preferably one that supports compression during relative angular rotation of the ankle plate and foot plate elements, such as during toe and heel roll, and also vertical compression, such as in response to vertical shock loads.

52 Claims, 7 Drawing Sheets



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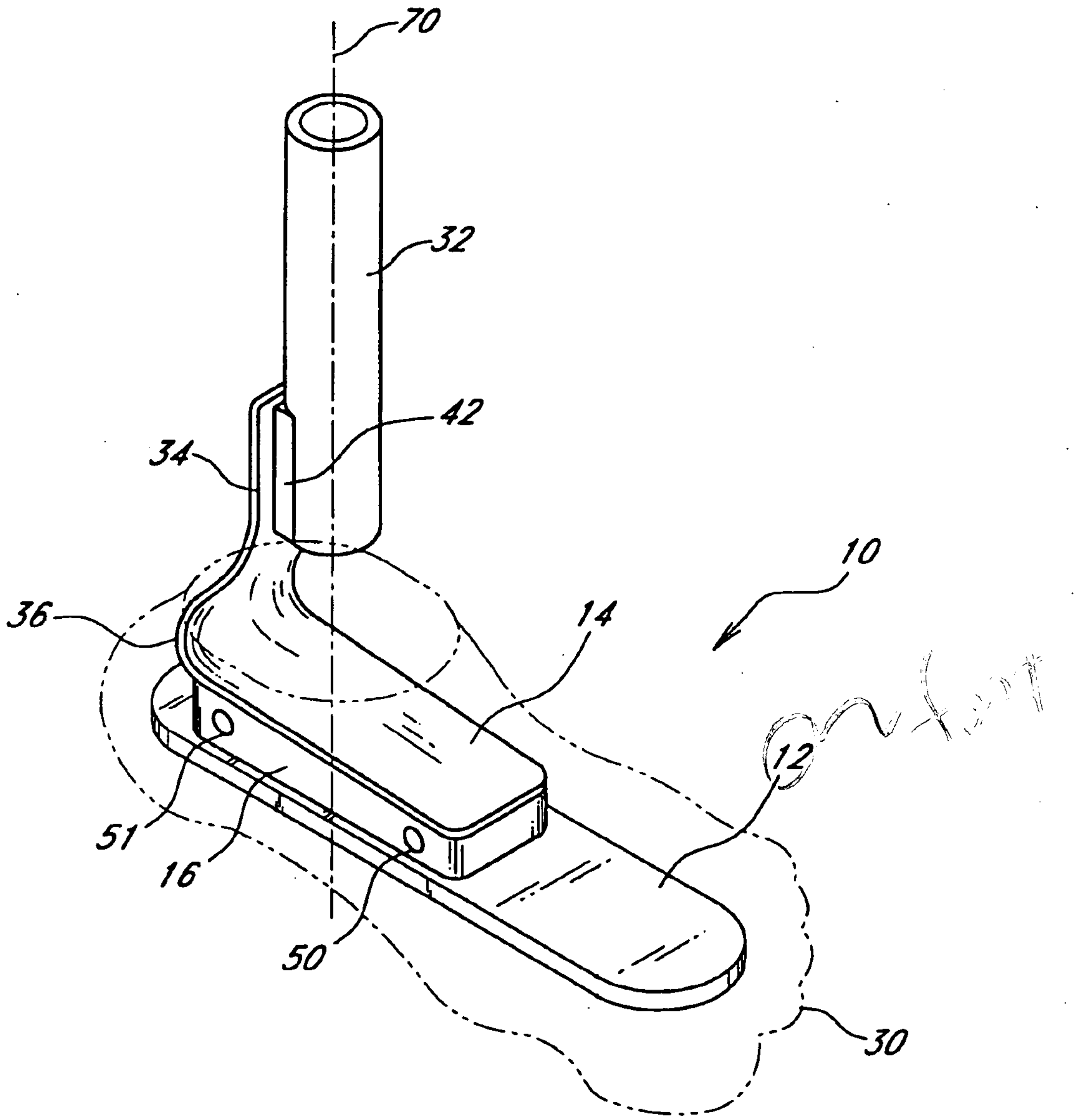
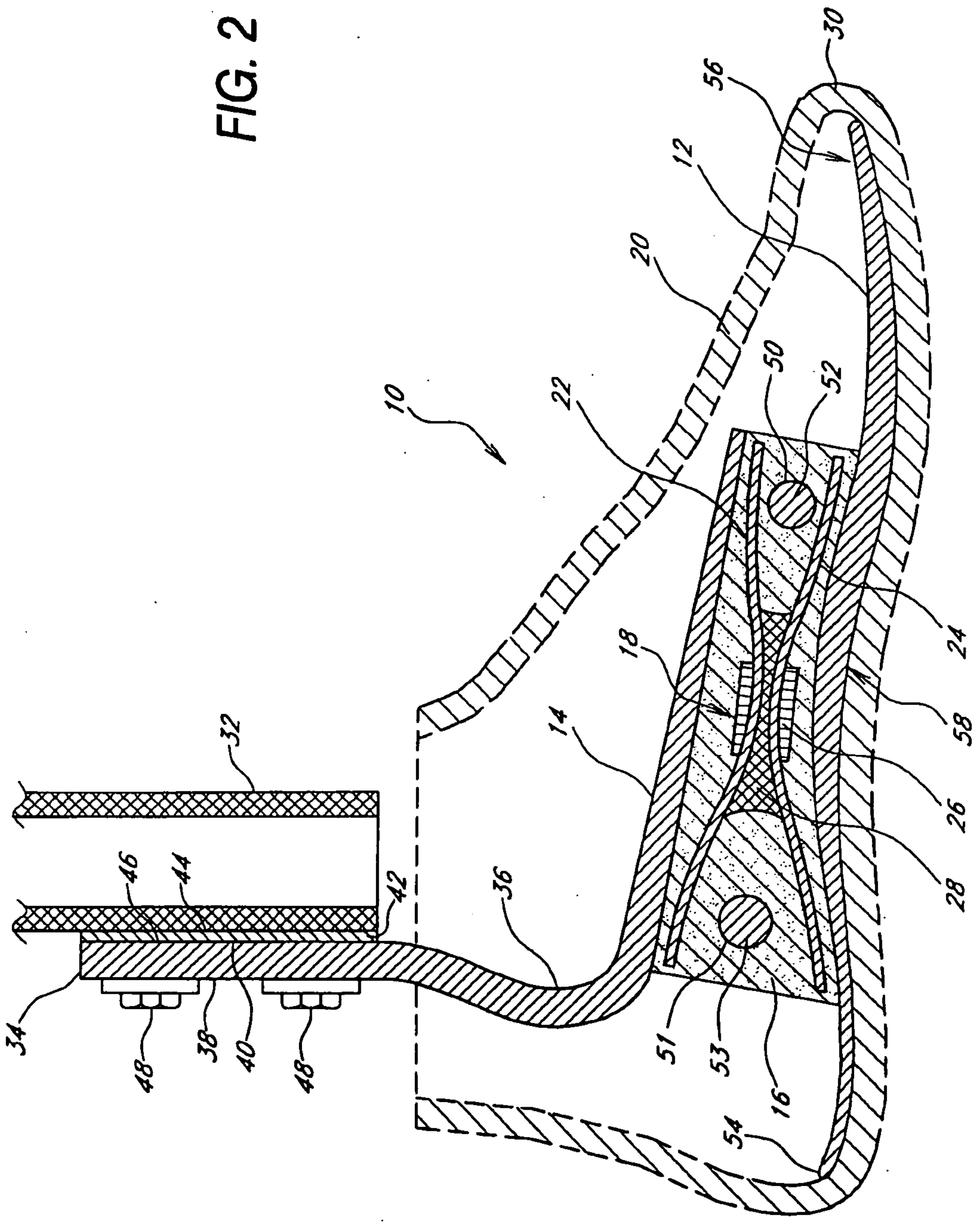


FIG. 1

FIG. 2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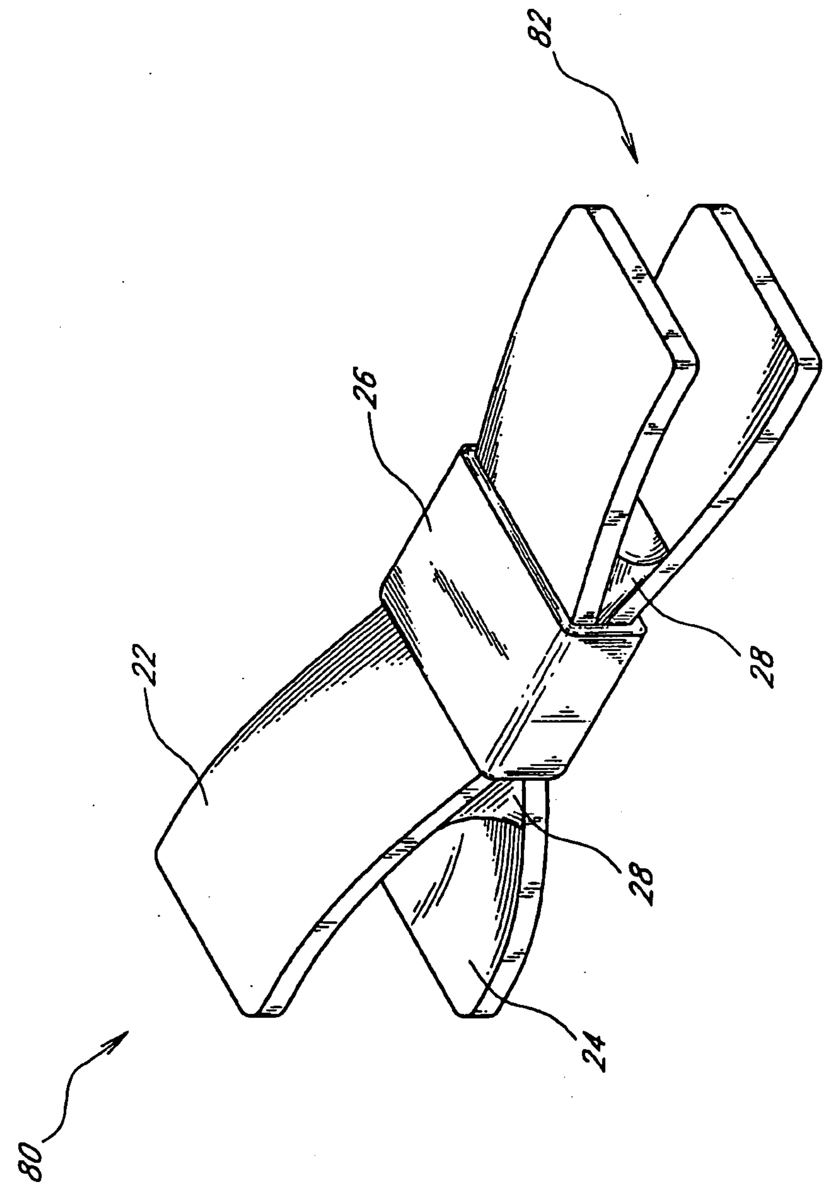

FIG. 3

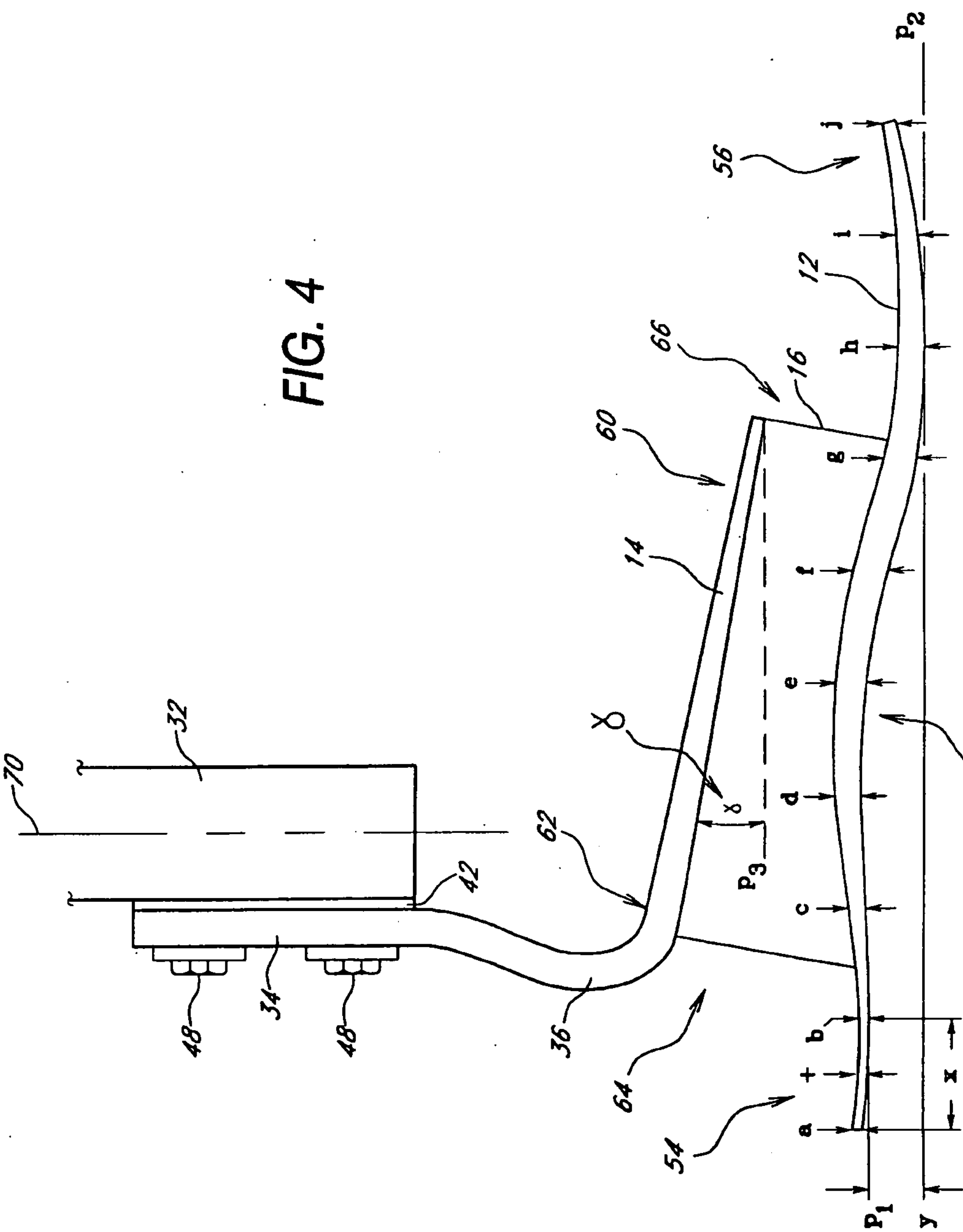
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FIG. 4

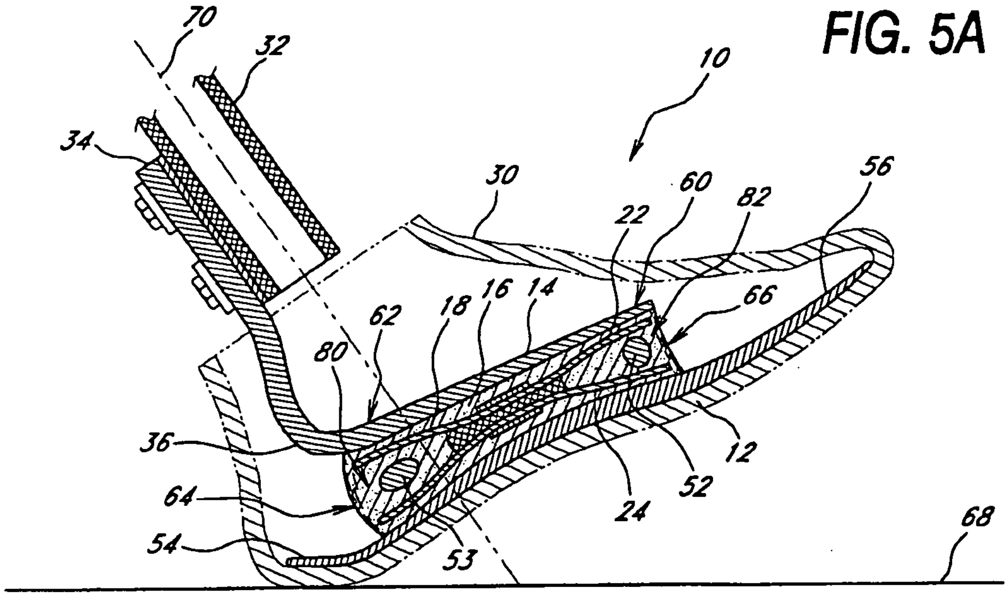
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FIG. 5A

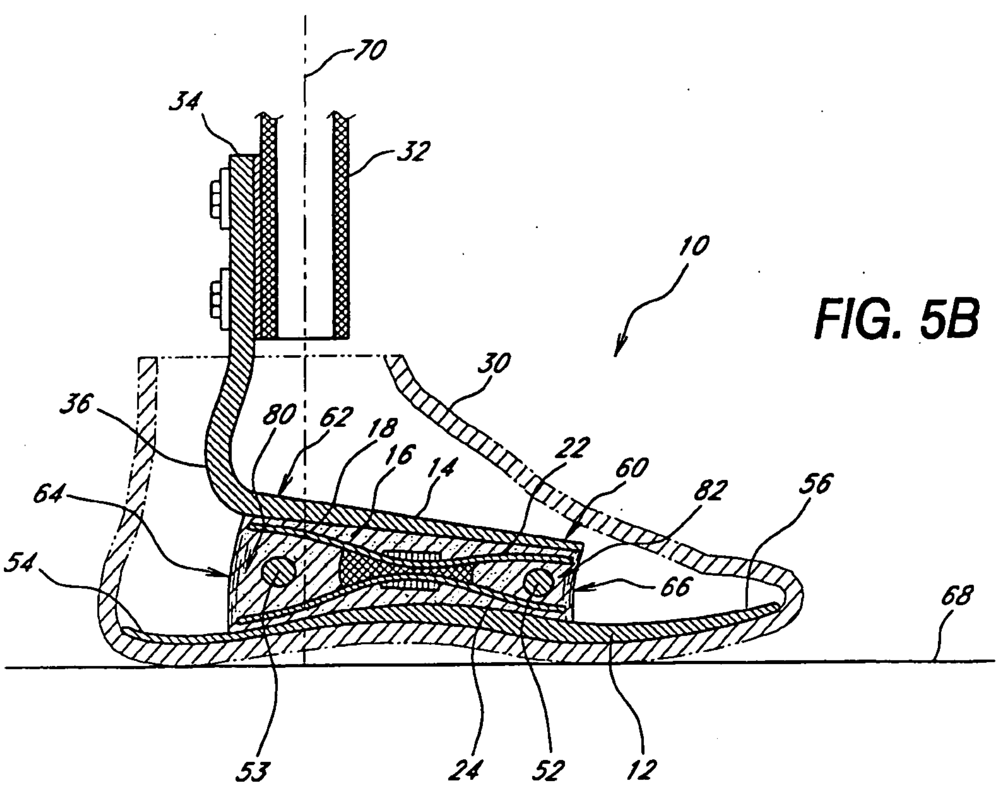
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FIG. 5B

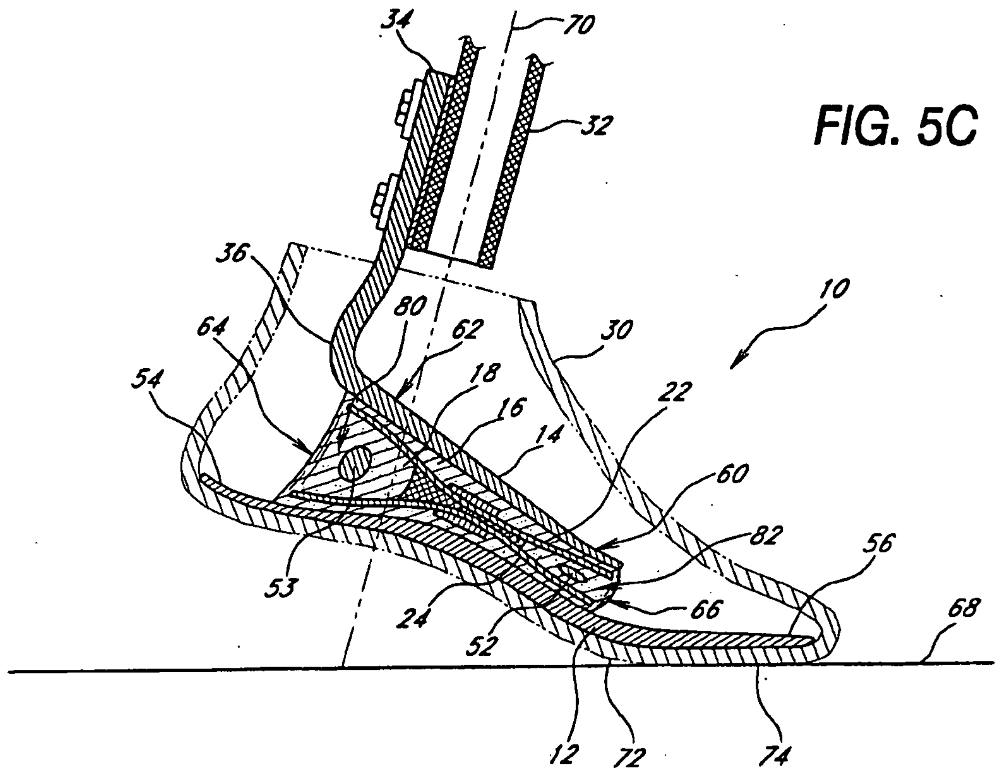
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FIG. 5C

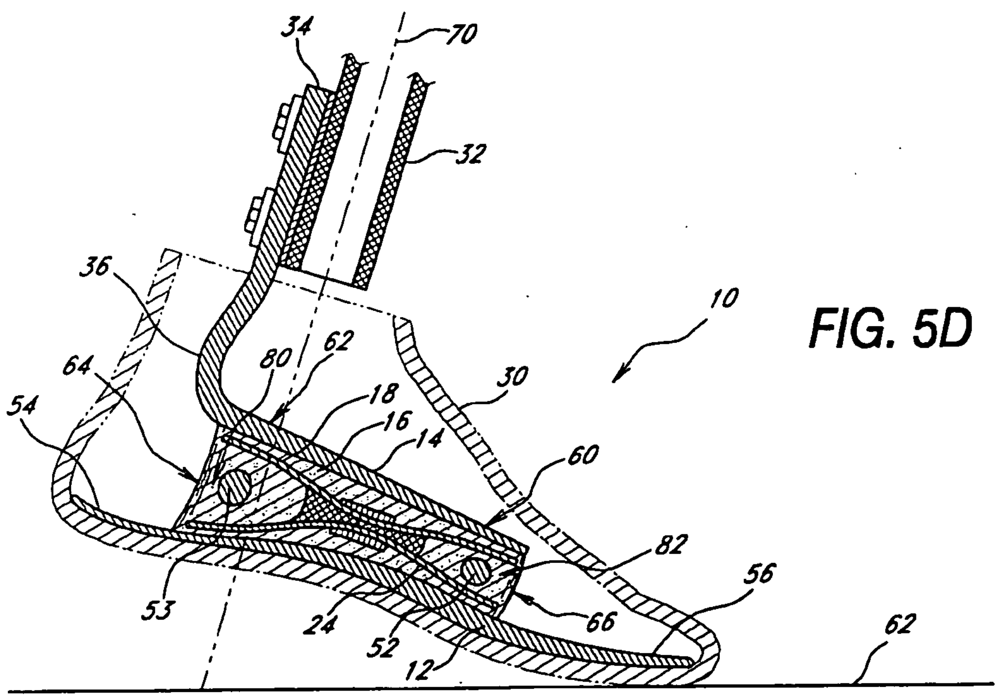
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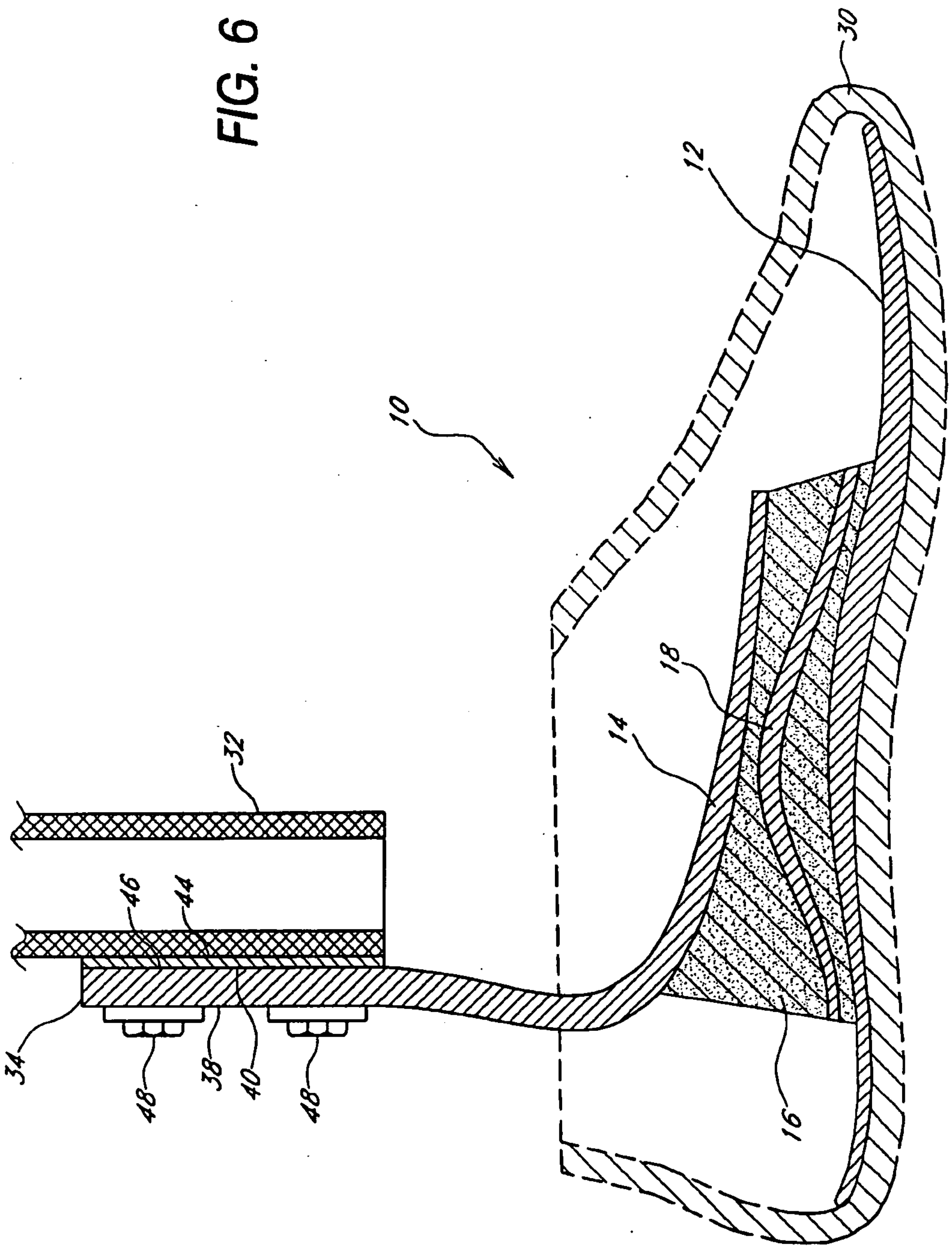
FIG. 5D

FIG. 6



ANKLE BLOCK WITH SPRING INSERTS

CROSS-REFERENCE TO PENDING APPLICATION

This application is a continuation of provisional application Ser. No. 60/081,472, filed Apr. 10, 1998.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to prosthetic feet and, more particularly, to a simply constructed, low-profile prosthetic foot having enhanced performance characteristics.

2. Description of the Related Art

In the prosthetics market, the conventional SACH (solid-ankle, cushion-heel) foot has been the most widely prescribed artificial foot over the past 35 years. The SACH foot generally includes a solid ankle and cushioned heel foot mounted to a limb along an approximate hinge axis taken through the ankle. The SACH foot has been popular precisely for its simplicity, and thus economy, but includes certain drawbacks in terms of dynamic response characteristics. Specifically, the low end SACH feet do not provide much energy storage and release, as do more sophisticated prosthetic feet.

Most modern foot prostheses incorporate some form of energy storage element for storing and releasing walking energy. Conventionally, this might consist of a spring-loaded ankle joint comprising metal coil springs or, more commonly, rubber compliance members. Inexpensive foot prostheses have also been devised having essentially a solid rubber or foam ankle block for storing and releasing walking energy. Such an ankle block has been disclosed in my issued patent titled PROSTHESIS WITH RESILIENT ANKLE BLOCK, U.S. Pat. No. 5,800,569, the entirety of which is incorporated by reference. A solid, compressible ankle block may be secured between upper and lower support members to provide resilient compression and energy storage and release. The use of an ankle block member provides significant manufacturing and cost advantages. However, for certain applications it is difficult to attain a desired level of spring compliance and energy return characteristics using a solid ankle block due to the inherent limitations of the materials involved in terms of elasticity, viscosity and maximum compression.

Therefore, it would be desirable to provide an ankle block having selectable compliance and energy return characteristics that may be varied over a wider range to accommodate the different weight, height and activity levels of amputees.

SUMMARY OF THE INVENTION

In response to the problems with the prior art, the present invention provides a simple, inexpensive prosthetic foot incorporating an ankle block with spring inserts. The ankle block is formed of compressible material having desired compliance and energy return characteristics. The ankle block is sandwiched between a foot element and an ankle element. One or more spring inserts are embedded inside the ankle block to increase the rigidity of the prosthetic foot and to improve the degree of energy storage and return. The shape of the spring inserts is preferably one that supports compression during relative angular rotation of the ankle plate and foot plate elements, such as during toe and heel roll, and also vertical compression, such as in response to vertical shock loads.

In one aspect of the present invention, a basic prosthetic foot is provided having enhanced performance characteristics generally comprising a lower foot plate, an upper ankle plate, a foam ankle block joining the two plates, and a spring element embedded in the ankle block. Both the foot plate and the ankle plate are constructed of strong, flexible material, preferably a laminate of composite material. The foot plate is sized approximately equal to a human foot being replaced, while the ankle plate has a similar width, but has a shorter length than the foot plate. The ankle block has a length and width approximately equal to the ankle plate and is aligned therewith. The spring element comprises two relatively flat carbon fiber composite members secured at their middle and separated at their ends. This gives the spring element a preferable shape of a bowtie or double wishbone. Preferably, an attachment member couples the ankle plate to a stump or lower-limb pylon of the wearer. During walking, the combination of the resilient ankle block with embedded spring element and flexible plates provides a smooth rollover from a heel-strike to a toe-off position.

In another aspect, the ankle block of a prosthetic foot may be provided with cylindrical openings both in the fore and aft positions of the ankle block. These openings enable the placement of additional inserts or stiffeners to give the block a desired rigidity. In a preferred embodiment, the foot element also has a tapered thickness. Further, the foot element comprises uplifted heel and toe ends and an arch region therebetween.

Further advantages and applications will become apparent to those skilled in the art from the following detailed description and the drawings referenced herein.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of the prosthetic foot of the present invention.

FIG. 2 is a cross-sectional view of the prosthetic foot of the present invention.

FIG. 3 is a perspective view of the spring element embedded in the ankle block of the present invention.

FIG. 4 is a side elevational view of the prosthetic foot more clearly showing a foot plate having a tapered thickness along its length.

FIG. 5A is a sectional view of the prosthetic foot in a heel-strike position of a walking stride.

FIG. 5B is a sectional view of the prosthetic foot in a flat position of a walking stride.

FIG. 5C is a sectional view of the prosthetic foot in a heel-off position of a walking stride.

FIG. 5D is a sectional view of the prosthetic foot in a toe-off position of a walking stride.

FIG. 6 is a cross-sectional view of an alternative embodiment of the prosthetic foot of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

With reference to FIGS. 1 and 2, a first embodiment of a prosthetic foot 10 of the present invention is shown in a perspective view and a cross-sectional side view, respectively. The prosthetic foot 10 generally comprises a lower foot plate 12 an upper, smaller ankle plate 14, an ankle layer or block 16 made of resilient material, connecting the foot plate 12 to the ankle plate 14, and a spring element 18 embedded within the ankle block 16. The foot plate 12 has a length and width roughly equal to the approximate length and width of the particular wearer's amputated foot and sized to fit within an outer, flexible cosmesis 30, shown in

phantom. The ankle plate 14 and the resilient ankle block 16 have approximately the same horizontal cross-sectional size. The ankle plate 14, ankle block 16, and spring element 18 are centered transversely with respect to and are generally positioned over the back half of the foot plate 12. The ankle block 16 is sandwiched between the foot plate 12 and the ankle plate 14 and is preferably glued or bonded to both plates using polyurethane adhesive or other known securement technologies.

The spring element 18 is a resilient support member inserted within the resilient ankle block 16. As shown in FIG. 3, the spring element 18 is preferably comprised of upper and lower plate-like members 22 and 24, each of which is relatively flat and has a substantially rectangular vertical projection. These members are secured at their center by a fastener 26 and separated at ends 80 and 82. The upper member 22 preferably has a curvilinear concave upward shape, while the lower member 24 preferably has a curvilinear concave downward shape. This gives the spring element 18 a substantially double wishbone or bowtie shape.

As shown in FIG. 1, the spring element 18 is completely embedded within the ankle block 16 so as not to be visible from the outside. Referring to FIG. 2, the spring element 18 extends substantially longitudinally across the length of the ankle block 16, and has a width substantially equal to the width of ankle block 16. The fastener 26 may comprise bolts, a weld, or any other fastening means as would be known to those skilled in the art. In the preferred embodiment, the fastener 26 is a strap which is laminated around the center portion of the two members 22, 24. A wedge member 28, preferably of a resilient elastomer, is placed between the two plate members 22, 24 to protect the inner surfaces of the members and to provide additional support to the spring element 18. The wedge 28 acts to provide leverage between the two plate members 22, 24, and enables adjustment of the flexing characteristics of the spring element 18, if desired. Alternatively, it may be bonded permanently in place or formed integrally with one or both of the plate members 22, 24, as desired. Although the spring element 18 has been described as having a double wishbone or bowtie configuration, other shapes and sizes may be appropriate for providing support to the ankle block 16. Furthermore, more than one spring element may be provided in the ankle block to provide support and energy return to the prosthetic foot 10.

As can be seen in FIGS. 1 and 2, the prosthetic foot 10 further comprises a pylon member 32 which can be secured to the stump of the amputee (not shown) and extends relatively downward therefrom in a generally vertical direction. The pylon member 32 in the preferred embodiment is of tubular construction having a substantially equal moment of inertia in all directions to restrict bending in all directions. The tubular member 32 is also preferably hollow so that it is relatively light in weight and utilizes less material which reduces the cost of production. The pylon member 32 is dimensioned so as to be interchangeable with a standard 30 mm pylon. Other configurations which impart rigidity, such as rectilinear cross sections having relatively larger moments of inertia about one or both transverse axes can also be utilized to obtain the benefits discussed herein. A centerline 70 through pylon 32, shown in FIG. 1, defines the downward direction of the application of force.

As shown in FIGS. 1 and 2, the ankle plate 14 is secured to the pylon member 32 through a vertically oriented upper attachment member 34. The upper attachment member 34 is attached to a curvilinear ankle section 36, which is connected to the ankle plate 14. Preferably, these three pieces are monolithically formed with one another for optimum strength and durability. The attachment member 34 has a rearward surface 38, as shown in FIG. 2, and a forward surface 40 substantially parallel thereto. The attachment member 34 is substantially rigid and capable of sustaining torsional, impact and other loads impressed thereupon by the prosthesis. In addition, the inherent rigidity of attachment member 34 prevents it from being distorted in any substantial way and causes the effective transmission of the aforesaid loads imposed thereupon to a suitable ancillary prosthetic pylon 32.

With reference to FIG. 2, the attachment member 34 is in the preferred embodiment vertically oriented so that it may be secured to the pylon member 32. A coupling device 42 is positioned at the lower end of the pylon member 32 which provides a flat surface upon which the vertical attachment member 34 can be secured. The coupling device 42 has one attachment surface 44 which mates with the cylindrical outer surface of the pylon member 32 and a second substantially flat attachment surface 46 which mates with the attachment member 34. In the preferred embodiment, attachment surface 44 is curved to closely mate with the outer surface of the tubular pylon member 32, and attachment surface 46 is flat to accommodate the forward surface 40 of the attachment member 34.

Desirably, the coupling device 42 is welded or bonded to the pylon member 32 and has two holes (not shown) into which two bolts 48 can be inserted and secured. The attachment member 34 also has two holes (not shown) which align with the holes on the coupling device to place and secure the two bolts 48 through the attachment member 34 and the coupling device 42. Other methods of securing the pylon member to the foot portion are contemplated, such as those disclosed in my prior issued U.S. Pat. No. 5,514,186, the entirety of which is incorporated by reference, as well as those utilizing integrally formed constructions.

As stated, the attachment member 34 monolithically formed with the ankle plate 14 is vertically aligned so that it extends relatively downward from the coupling device 42 on the pylon member 32. As shown in FIG. 2, the thickness of the attachment member 34 along this vertical section is relatively greater than the thickness of the ankle plate 14 substantially horizontally aligned along the foot portion. The attachment member 34 is also made relatively thicker to support the vertical load imposed on the prosthetic device as well as to restrict undue bending at this juncture. The entire upper vertically-aligned section of attachment member 34 is preferably of substantially uniform thickness and width.

The tubular pylon member 32 is preferably removable from the prosthetic device such that the pylon member can be replaced without replacing the remainder of the prosthetic device. This permits Applicant's invention to be utilized in a broader range of applications. For instance, the tubular member of Applicant's invention can be cut and adapted for use by amputees having different stump lengths including growing amputees. The prosthetist merely needs to cut a standard tubular pylon to the appropriate length. Moreover, this eliminates the need to manufacture as a part of the prosthesis a long rigid leg section. Thus, fewer materials are needed to manufacture the prosthesis of Applicant's invention resulting in reduced manufacturing costs.

The preferred embodiment further comprises cylindrical slots or openings 50, 51 in the fore and aft portions of the ankle block 16, respectively, as shown in FIG. 2, to accommodate insertion of stiffeners 52, 53. The cylindrical openings 50, 51 are disposed horizontally in a direction generally

transverse to a forward walking motion, and between upper and lower plate members 22 and 24. Stiffeners 52, 53 can be removably placed in these openings to provide additional support and rigidity to the prosthetic foot 10, and also to modify the spring characteristics of the prosthetic foot. For instance, additional energy storage and return can be provided for a more active amputee by inserting stiffeners 52, 53 into ankle block 16 having a higher spring constant. On the other hand, when more control is desired, stiffeners with a lower spring constant may be inserted to produce an ankle block 16 with greater dampening characteristics. Alternatively, the cylindrical openings 50, 51 may remain empty, thereby making the compliance characteristics dependent solely on the ankle block 16 and the spring element 18.

Preferred Materials and Fabrication

Both the foot plate 12 and the ankle plate 14 are preferably formed of a flexible material so that flexing of the plates tends to relieve extreme shear stresses applied to the interfaces between the ankle block 16 and the plates 12, 14. Both the foot plate 12 and the ankle plate 14 are preferably constructed of fiberglass which provides strength and flexibility. The preferred material for the ankle plate 14 and the foot plate 12 is a vinyl ester based sheet molding compound, such as Quantum #QC-8800, available from Quantum Composites of Midland, Mich. Alternatively, the plates may be formed by a plurality of lamina embedded in an hardened flexible polymer. In other arrangements, the plates may be formed of other materials such as carbon fiber composites as may be apparent to one skilled in the art. The desirable properties of the plates are that they are relatively resilient so as to withstand cracking upon application of repeated bending stresses yet have sufficient flexibility to enhance the performance characteristics felt by the wearer in conjunction with the properties of the resilient ankle block. The pylon member 32 is preferably made of a stiff material such as a laminate of fiber reinforced composite. Stiffness in the pylon member 32 can also be provided by a stiffer and more dense material.

The ankle block 16 is sandwiched between the foot plate 12 and the ankle plate 14 as shown in FIGS. 1 and 2 and is preferably bonded to both plates. The ankle block is preferably formed of urethane, rubber or other suitable material having desired compliance and energy return characteristics. A preferred material for the ankle block is expanded polyurethane foam such as cellular Vulkolka® Pur-Cell No. 15-50, with a density of approximately 500 kg/m^3 as available from Pleiger Plastics Company of Washington, Pa. Alternatively, the ankle block 16 may be molded or fabricated from a wide variety of other resilient materials as desired, such as natural or synthetic rubber, plastics, honeycomb structures or other materials. Cellular foam, however, provides a high level of compressibility with desirable viscoelastic springiness for a more natural feeling stride without the stiffness drawbacks and limited compression associated with solid elastomeric materials. Furthermore, the cellular nature of a foam block makes it lighter than solid elastomers. Foam densities between about 150 and 1500 kg/m^3 may be used to obtain the benefits of the invention taught herein.

The spring element 18 is preferably made from a highly resilient material that is capable of supporting compression during relative angular rotation of the upper and lower members 12 and 14, such as during toe and heel roll, and also vertical compression such as in response to vertical shock loads. One preferred material is carbon fiber composites such as woven fiber mats and chopped fiber in an epoxy matrix. However, other materials with similar strength and weight characteristics will be known to those skilled in the art and may be used with efficacy. For instance, other filament types may be used, such as glass, Kevlar and nylon by way of example, to ensure lightweight and structural and dynamic characteristics consistent with the needs of a particular amputee. The wedge 28 may be fabricated from a wide variety of resilient materials, including natural and synthetic rubber, elastomeric polyurethanes, or the like.

The ankle block 16 containing spring element 18 may be fabricated by injecting a polyurethane elastomer into a mold allowing it to cure. The spring element 18 may be inserted into the mold prior to injection of the polyurethane so that during curing, the polyurethane bonds to the spring member. Cylindrical slots or openings 50, 51 for insertion of stiffeners 52, 53 may be provided in ankle block 16 by inserting cylindrical plugs into the block prior to injection of polyurethane. Alternatively, openings may be provided in the block after curing simply by cutting or drilling away portions of the ankle block.

The stiffeners provided in the openings are preferably tubes of foam material having a density chosen according to desired compliance characteristics. A preferable material is expanded polyurethane having a foam density between about 150 and 1500 kg/m^3. More preferably, a density of about 250 to 750 kg/m^3 is preferred to provide adequate adjustment of the energy storage and return characteristics of the prosthetic foot.

Preferred Dimensions

As illustrated in FIG. 4, the foot plate 12 is preferably of curvilinear shape. The thickness t of foot plate 12 is preferably tapered along its length, and the tapered profile corresponds approximately to the weight of the amputee. That is, for a heavier amputee, the thicknesses along the length would be greater than for a lighter weight amputee. Generally, the weight groups may be classified as light, medium, or heavy.

Table I below presents preferred groupings, as module sizes C/D/E, of cosmesis sizes corresponding to a male "A" width shoe last. The sizes are presented by length L, width B at the forefoot and width H at the heel of the cosmesis.

TABLE I

Cosmesis Sizes for Male "A" Width Shoe Last

MODULE	LENGTH L (cm)	WIDTH B (cm)	WIDTH H (cm)
C	22	2.88	2.19
	23	3.00	2.25
	24	3.12	2.31
D	25	3.25	2.44
	26	3.38	2.50
	27	3.50	2.56
E	28	3.62	2.69
	29	3.75	2.75
	30	3.88	2.81

Table II below presents preferred module sizes for various weight groups of amputees.

TABLE II

Modules vs. Weight Groups

MODULE	WEIGHT GROUP LIGHT	MEDIUM	HEAVY
C	CL	CM	—
D	DL	DM	DH
E	—	EM	EH

Table III below presents preferred taper thicknesses (t) for an average or "DM" size foot plate 12 taken at positions spaced by distance x=1 inch (2.54 cm).

TABLE III

Taper Thickness t for DM Foot Plate

POSITION (x = 2.54 cm)	THICKNESS t (cm)
a	0.16
b	0.16
c	0.32
d	0.52
e	0.69
f	0.78
g	0.71
h	0.60
i	0.48
j	0.28

The foot plate 12 has a heel end 54, toward the left in FIG. 4, which is concave-upward or slightly uplifted from a horizontal plane P_1 tangential to the heel end 54 of the foot plate 12. Similarly, a toe end 56, to the right of FIG. 4, is concave upward or somewhat uplifted from a horizontal plane P_2 tangential to the front portion of the foot plate 12. An arch section 58 is formed between the heel and toe ends and is preferably concave-downward, as shown.

It is understood that within the cosmesis 30 (not shown), the tangent plane P_1 of the heel end 54 is slightly raised a distance y relative to the tangent plane P_2 of the toe end 56, as shown. The DM-sized foot plate of Table III, for example, has y=0.5 inches (1.27 cm). The foot plate 12 is preferably 0.25 inches (0.63 cm) from the bottom or sole of the cosmesis 30. The cosmesis 30 may be insert molded using an anatomically sculpted foot shape, with details and sizing based on a master pattern and/or digitized data representing typical foot sizes.

An intermediate region 58 comprising the arch portion of the foot plate 12 has the greatest thickness of the foot plate 12. The curvature of the arch region 58 is defined by the cosmesis or shoe sole profile, and generally corresponds to selected ranges of human foot lengths.

The foot plate 12 of prosthesis 10 preferably has a length between about 5 and 15 inches (about 13 and 38 cm), more preferably between about 8 and 12 inches (about 20 and 30 cm) for the foot sizes given in Table I. The width of foot plate 12 is preferably about 1 to 4 inches (about 2.5 to 8 cm). For the example given in Table III for a DM-sized foot plate 12 the length of the plate 12 is approximately 9 inches (about 23 cm) and its width is about 2 inches (about 5 cm). The foot plate 12 has a thickness between about 0.05 and 0.4 inches (about 0.1 and 1 cm), which more preferably may be tapered as indicated in Table III.

The ankle plate 14 of prosthesis 10 is substantially planar, and is preferably shorter in length than the foot plate 12 and has a thickness also defined by the weight group of the wearer. The thickness of the ankle plate is preferably about 0.05 to 0.4 inches (0.1 to 1 cm). More preferably, the corresponding ankle plate 14 in the present example is about 0.2 inches (about 0.5 cm) thick at rear portion 62, tapering to a thickness of about 0.1 inches (about 0.25 cm) at front portion 60. The ankle plate 14 preferably has a length of about 3 to 7 inches (about 8 to 18 cm) and a width of about 1 to 3 inches (about 2.5 to 8 cm), more preferably having length-width dimension of approximately 5x2 inches (about 13x5 cm). The ankle plate 14 is positioned at an angle such that its front tip 60 is located closer to the foot plate 12 than its rear tip 68. Relative to plane P_3 shown in FIG. 4, the rear tip is preferably raised an angle γ of about 5 to 30 degrees, and more preferably, about 10 degrees.

The ankle block 16 is generally sized such that its upper surface is planar and corresponds to the length and width of the ankle plate 14. The lower surface of the ankle block 16 is substantially curvilinear to mate with the curvilinear surface of foot plate 12. In the present example, the block 16 has a preferred thickness, at its front 66, of about 1 to 3 inches (about 2.5 to 8 cm), more preferably about 1.3 inches (about 3.4 cm). Its thickness tapers to a minimum of about 0.5 to 1 inch (about 1 to 2.54 cm), more preferably about 0.8 inches (about 2 cm) adjacent arch portion 58. The rear 64 of the block 16 is preferably about 1 to 4 inches (about 2.5 to 10 cm) thick, more preferably about 2.6 inches (about 6.6 cm) thick, which is about twice the thickness of the front portion 66 of the block 16. This gives the ankle block a substantially wedge shape. The greater thickness at the rear of block 16 is provided to impart additional support in the rear portion 64 of the ankle block due to greater compressive forces on the rear of the foot prosthesis caused by off-axis application of force relative to axis 70 during heel strike (see FIG. 5A).

The ankle block 16 may be provided in varying heights or thicknesses, as desired, but is most effective with a thickness of between about 1 and 4 inches (about 2.54 and 10 cm). The front portion and rear surfaces of ankle block 16 are preferably angled according to the angle γ defined by the plane P_3 and the ankle plate 14. In other words, the ankle block has front and rear surfaces which are preferably sloped forward at an angle γ from vertical. The ankle block thus provides a relatively stiff, yet flexible ankle region which can be customized for various wearers. Heavier wearers may require a denser resilient material for the ankle block, while lighter wearers may require a less dense material or less thickness.

As shown in FIGS. 2 and 3, the spring element 18 is positioned in the ankle block such that the center of the spring element 18, at the position of fastener 26, is located approximately above the arch portion 58 of foot plate 12. The two members 22, 24 of the spring element 18 preferably have a constant thickness of about 0.05 to 0.2 inches (about 0.1 to 0.5 cm). The distance between the two members at front end 82, when no load is impressed onto the foot 10, is preferably about 0.5 and 2 inches (about 1 to 5 cm), more preferably about 0.7 inches (about 1.8 cm). At rear end 80, when no load is impressed on the foot 10, the distance between members 22 and 24 is about 1 to 3 inches (about 2.5 to 7.5 cm), more preferably about 1.4 inches (about 3.5 cm). As described in further detail below, when the foot is in a heel-strike position, the rear end 80 of the spring element is compressed. When the foot is in a toe-off position, the forward end 82 of the spring element is compressed.

The lengths, widths and thicknesses of the foot plate 12 ankle plate 14, ankle block 16 and spring element 18 may be customized for the wearer according to his/her foot size as well as the approximate weight group of the wearer. Likewise, the material choice and size for these elements may be varied according to the wearer's foot size and weight.

The cylindrical openings 50, 51 provided in the fore and aft portions of ankle block 16 preferably have a diameter of about 0.1 to 0.4 inches (about 0.25 to 1 cm), and more preferably, about 0.2 inches (about 0.5 cm). While the openings 50 and 51 shown in FIG. 2 have the same diameter, the diameters of the openings may be different to accommodate different sized stiffeners. For instance, the diameter of opening 51 may be made larger than the diameter of opening 50 to correspond with the greater volume of ankle block 16 in rear portion 64.

Performance Characteristics

To more fully explain the improved performance characteristics of the present prosthetic foot 10, FIGS. 5A–5D show "snapshots" of a prosthetic foot in several positions of a walking stride. More particularly, FIG. 5A shows a heel-strike position, FIG. 5B shows a generally flat or mid-stance position, FIG. 5C shows a heel-off position, and FIG. 5D shows a toe-off position. Throughout the various positions shown for a walking stride, the present prosthetic foot 10 provides a smooth and generally life-like response to the wearer. During a walking stride, the ankle block 16 transmits the forces imparted thereon by the foot plate 12 and ankle plate 14, and experiences a gradual rollover, or migration of the compressed region, from rear to front.

With specific reference to FIG. 5A, a first position of a walking stride generally entails a heel strike, wherein the wearer transfers all of his or her weight to the heel of the leading foot. In this case, a rear portion 54 of the foot plate 12 comes in contact with a ground surface 68, albeit through the cosmesis 30. The flexible nature of the foot plate 12 allows it to bend slightly in the rear portion 54, but most of the compressive stresses from the weight of the wearer through the prosthetic foot 10 to the foot plate 12 are absorbed by a rear region 64 of the ankle block 16 with spring element 18. The spring element 18 in the rear portion contracts, such that the distance between members 22 and 24 at rear end 80 decreases. In a front region 66 of the ankle block 16, the spring element 18 may expand slightly such that the distance between members 22 and 24 at front end 82 increases. Front portion 66 of the ankle block 16 experiences a stretching, or tension, due to the attachment along the entire lower edge of the ankle block with the foot plate 12 while rear portion 64 experiences compression. The contraction of the spring element 18 at end 80 and ankle block 16 at end 64 allows the prosthesis 10 to absorb and store energy from the compressive stresses during heel strike. Further, a slight amount of bending may occur in a rear region 68 of the ankle plate 14. The rear stiffener 53 between members 22 and 24 is compressed so as to provide necessary support to the foot prosthesis and to prevent separation of the members 22, 24 from the wedge 28. Front stiffener 52 is slightly stretched substantially vertically due to the tension forces at front portion 66 of ankle block 16.

Next, in FIG. 5B, the wearer reaches a generally flat-footed or mid-stance position, whereby the foot plate 12 contacts the ground 68 along substantially its entire length, again through the cosmesis 30. In this position the weight of the wearer is directed substantially downwardly, so that the compression along the length of the ankle block 16 is only slightly greater in the rear portion 64 than in front portion 66, due to the off-center application of force. In both the fore and rear ends of spring element 18, the members 22 and 24 are compressed towards each other, with the rear end 80 being slightly more compressed from its original position than the forward end 82. Likewise, stiffeners 52 and 53 are compressed due to the downward application of force. Although this view freezes the compressive stress distribution as such, in reality the weight of the wearer is continually shifting from behind the centerline 70 of the attachment member 34 to forward thereof. Thus, as the wearer continues through the stride, the compression of the ankle block 16 and the elements embedded within travels from the rear portion 64 toward the front portion 66. This migration of the compressed region can be termed "rollover."

In a next snapshot of the walking stride, FIG. 5C shows the prosthetic foot 10 in a "heel-off" position. This is the instant when the wearer is pushing off using ball 72 and toe 74 regions of the foot. Thus, a large compressive force is generated in the front region 66 of the ankle block 16, causing the rear region 64 to experience a large amount of separation or tension. Similarly, the spring element 18 at the rear end 80 expands between the two members 22, 24, while it compresses in the front end 82. The front tip 56 of the foot plate 12 may bend substantially to absorb some of the compressive stresses. Likewise, the front tip 60 of the ankle plate 14 may bend somewhat at this point. It is important to note that although the ankle block 16 absorbs a majority of the compression generated by the wearer, the foot plate 12 and ankle plate 14 are designed to work in conjunction with the resilient ankle block and spring element and provide enhanced dynamic performance. Further, the flexing of the foot plate 12 and ankle plate 14 relieves some of the extreme shear stresses applied to the interfaces between the ankle block 16 and plates, thus increasing the life of the bonds formed therebetween. The stiffener 52 located in the front 66 of the ankle block 16 compresses so as to limit compression of front end 82, giving the wearer balance and to prevent separation of the members 22, 24 from the wedge 28. Stiffener 53 extends due to the separation of ankle block 16 in rear portion 64.

In FIG. 5D, a final position of the walking stride is shown, wherein the prosthetic foot 10 remains in contact with the ground 68, but some of the weight of the wearer is being transferred to the opposite foot, which has now moved forward. In this "toe-off" position, there is less bending of the front tip 56 of the foot plate 12 and less compression of the front portion 66 of the ankle block 16 and front end 82 of spring element 18. Likewise, the front tip 60 of the ankle plate 14 may flex a slight amount, depending on the material and thickness utilized. The region of highest compression of the ankle block 16 remains at the farthest forward region 66, but it is reduced from the compression level of the heel-off position of FIG. 5C. Thus, the rear portion 64 of the ankle block 16 experiences a small amount of tension or spreading.

It can now be appreciated that the "feel" of the present prosthetic foot is greatly enhanced by the cooperation between the foot plate, ankle plate, ankle block and spring inserts. As the wearer continues through the walking stride the dynamic response from the prosthetic foot is smooth as the ankle block with spring inserts compresses in different regions. Further, the flexing of the ankle and foot plates assist in smoothly transmitting the various bumps and jars found in uneven walking surfaces.

Alternative Embodiments

It will be appreciated that alternative embodiments of a prosthetic foot having an ankle block with a spring insert are

also encompassed by this invention. One such alternative embodiment is shown in FIG. 6. Reference numerals for FIG. 6 generally correspond to the reference numerals used in FIGS. 1–5D for like elements. Thus, the prosthetic foot **10** shown in FIG. 6 generally comprises a lower foot plate **12** an upper, smaller ankle plate **14**, an ankle layer or block **16** made of resilient material, connecting the foot plate **12** to the ankle plate **14**, and a spring element **18** embedded within the ankle block. The foot plate **12** has a length and width roughly equal to the approximate length and width of the particular wearer's amputated foot and sized to fit within an outer, flexible cosmesis **30**, shown in phantom. As shown in FIG. 6, the ankle plate **14** has a substantially arcuate curvature extending from the integrally formed attachment member **34** to the front of the ankle plate **14**.

More particularly, the spring element **18** as illustrated in FIG. 6 is a resilient support member inserted within the resilient ankle block **16**. The spring element **18** shown in FIG. 6 is preferably a plate-like member with a curvilinear concave downward shape and a substantially rectangular vertical projection. The spring element **18** is preferably made from a carbon fiber composite material such as described hereinbefore, although other similar materials may be used as well.

The embodiments illustrated and described above are provided merely as examples of certain preferred embodiments of the present invention. Other changes and modifications can be made from the embodiments presented herein by those skilled in the art without departure from the spirit and scope of the invention as defined by a fair reading of the appended claims.

What is claimed is:

1. A prosthetic foot for attaching to a socket or pylon of a lower-limb amputee, comprising:

a foot plate element having a length approximately equal to the length of a human foot, the foot plate element comprising a resilient material capable of flexing along its length;

an ankle plate element having a length substantially shorter than the foot plate element;

an ankle block comprising a relatively soft, compressible material sandwiched between the ankle plate element and the foot plate element, the ankle block providing energy storage and support and connection between the foot plate element and the ankle plate element; and

a spring element embedded within the ankle block for providing additional energy storage and support, said spring element having a posterior portion configured to compress during heel-strike, and an anterior portion configured to compress during toe-off;

whereby the foot plate element, the ankle block, and the spring element flex in a cooperative manner to provide substantially smooth and continuous rollover transition from heel-strike to toe-off.

2. The prosthetic foot of claim **1**, wherein the foot plate element has a tapered thickness along its length, such that the thickness increases from a heel section to an arch section and decreases from the arch section to a toe section.

3. The prosthetic foot of claim **2**, wherein the heel and toe sections are formed substantially concave-up and the arch section is formed substantially concave-down.

4. The prosthetic foot of claim **1**, wherein the ankle block has a substantially planar upper surface and a curvilinear lower surface, the upper surface mating with a bottom surface of the ankle plate element, the lower surface mating with a top surface of the foot plate element.

5. The prosthetic foot of claim **1**, wherein the ankle plate element, the ankle block and the spring element are centered transversely with respect to and are generally positioned over a back half of the foot plate element.

6. The prosthetic foot of claim **1**, wherein the ankle block is made of a foam block having a density between about 150 and 1500 kg/m^3.

7. The prosthetic foot of claim **1**, wherein the spring element is formed from a carbon fiber composite material.

8. The prosthetic foot of claim **1**, wherein the spring element comprises upper and lower relatively flat members secured at their center by a fastener and separated at their ends.

9. The prosthetic foot of claim **8**, wherein the upper member is substantially curvilinear concave upward and the lower member is substantially curvilinear concave downward.

10. The prosthetic foot of claim 1, further comprising at least one opening extending through the ankle block adapted to receive a stiffener for adjusting the spring characteristics of the prosthetic foot.

11. The prosthetic foot of claim **10**, wherein a first and second cylindrical opening extend through the ankle block, the first opening being positioned in a fore portion of the block and the second opening being positioned in a rear portion of the block.

12. The prosthetic foot of claim **11**, wherein tubular stiffeners are placed in the openings.

13. A prosthetic foot, comprising:

an upper plate;

a lower plate;

a compressible layer formed of a compressible material, said compressible material connected to the upper plate and the lower plate and separating the upper plate from the lower plate; and

a spring element made of resilient material embedded within the compressible layer and spaced apart from the upper and lower plates, said spring element configured to store and release walking energy during ambulation of said prosthetic foot.

14. The prosthetic foot of claim **13**, wherein the lower plate has a length and a width roughly equal to the approximate length and width of an amputated foot.

15. The prosthetic foot of claim **13**, wherein the upper plate and the compressible layer have approximately the same cross-sectional size.

16. The prosthetic foot of claim **13**, wherein the compressible layer is made of a foam material having a density between about 150 and 1500 kg/m^3.

17. The prosthetic foot of claim **13**, wherein the spring element is made of a carbon fiber material.

18. The prosthetic foot of claim **13**, wherein the spring element has a substantially double wishbone shape.

19. The prosthetic foot of claim **13**, wherein the spring element is a plate-like member with a curvilinear concave downward shape.

20. The prosthetic foot of claim **13**, wherein the spring element is a foam material having a density between about 150 and 1500 kg/m^3.

21. The prosthetic foot of claim **13**, wherein the spring element is a tubular member inserted into the compressible layer.

22. A prosthetic foot including a resilient ankle block for separably mounting between a foot plate and an ankle plate of a prosthetic foot for providing resilient kinematic support to an amputee relative to a ground surface, the ankle block comprising a block of resilient material and at least one

spring insert embedded within the block of resilient material, said spring insert configured to store and release walking energy during ambulation of said prosthetic foot, said ankle block being substantially the sole means of connection and support between said foot plate and said ankle plate.

23. The prosthetic foot of claim 22, wherein the block of resilient material is an expanded polyurethane having a density between about 150 and 1500 kg/M^3.

24. The prosthetic foot of claim 23, wherein the expanded polyurethane has a density of about 500 kg/m^3.

25. The prosthetic foot of claim 22, wherein a first spring insert comprises upper and lower substantially plate-like members joined at their center and separated at their ends, the upper member being substantially curvilinear concave upward and the lower member being substantially curvilinear concave downward.

26. The prosthetic foot of claim 25, wherein the first spring insert is made of a carbon fiber composite material.

27. The prosthetic foot of claim 25, wherein a second spring insert comprises at least one tubular stiffener.

28. The prosthetic foot of claim 27, wherein a first tubular stiffener is positioned in a fore region of the ankle block between the upper and lower substantially plate-like members, and a second tubular stiffener is positioned in an aft region of the ankle block between the upper and lower substantially plate-like members.

29. The prosthetic foot of claim 28, wherein the first and second tubular stiffeners are made of an expanded polyurethane having a density between about 150 and 1500 kg/m^3.

30. The prosthetic foot of claim 29, wherein the first and second tubular stiffeners are made of an expanded polyurethane having a density of between about 250 and 750 kg/m^3.

31. The prosthetic foot of claim 22, wherein the at least one spring element is a plate-like member having a substantially curvilinear downward shape.

32. A prosthetic foot, comprising:

a support plate made of a resilient material and having a length approximately equal to the length of a human foot;

a layer of compressible material mounted to the support plate; and

a spring element comprising at least one substantially plate-like member embedded within the layer of compressible material, said plate-like member configured to store and release walking energy.

33. The prosthetic foot of claim 32, wherein the layer of compressible material is foam.

34. The prosthetic foot of claim 32, wherein the spring element is made of a carbon fiber material.

35. The prosthetic foot of claim 32, wherein the spring element comprises a pair of substantially plate-like members, the plate-like members being secured at their center and separated at their ends.

36. The prosthetic foot of claim 32, wherein the at least one substantially plate-like member has a curvilinear concave downward shape.

37. A prosthetic foot for attaching to a socket or pylon of a lower-limb amputee, comprising:

a foot plate element having a length approximately equal to the length of a human foot, the foot plate element comprising a resilient material capable of flexing along its length;

an ankle plate element having a length substantially shorter than the foot plate element;

an ankle block comprising a relatively soft, compressible material sandwiched between the ankle plate element and the foot plate element, the ankle block providing energy storage and support and connection between the foot plate element and the ankle plate element; and

a spring element embedded within the ankle block for providing additional energy storage and support, said spring element being formed from a carbon fiber composite material;

whereby the foot plate element, the ankle block, and the spring element flex in a cooperative manner to provide substantially smooth and continuous rollover transition from heel-strike to toe-off.

38. A prosthetic foot for attaching to a socket or pylon of a lower-limb amputee, comprising:

a foot plate element having a length approximately equal to the length of a human foot, the foot plate element comprising a resilient material capable of flexing along its length;

an ankle plate element having a length substantially shorter than the foot plate element;

an ankle block comprising a relatively soft, compressible material sandwiched between the ankle plate element and the foot plate element, the ankle block providing energy storage and support and connection between the foot plate element and the ankle plate element; and

a spring element embedded within the ankle block for providing additional energy storage and support, said spring element comprising upper and lower relatively flat members secured at their center by a fastener and separated at their ends;

whereby the foot plate element, the ankle block, and the spring element flex in a cooperative manner to provide substantially smooth and continuous rollover transition from heel-strike to toe-off.

39. The prosthetic foot of claim 38, wherein the upper member is substantially curvilinear concave upward and the lower member is substantially curvilinear concave downward.

40. A prosthetic foot, comprising:

an upper plate;

a lower plate;

a compressible layer connected to the upper plate and the lower plate and separating the upper plate from the lower plate; and

a spring element made of resilient material embedded within the compressible layer and spaced apart from the upper and lower plates, said spring element being made of a carbon fiber material.

41. A prosthetic foot, comprising:

an upper plate;

a lower plate;

a compressible layer connected to the upper plate and the lower plate and separating the upper plate from the lower plate; and

a spring element made of resilient material embedded within the compressible layer and spaced apart from the upper and lower plates, said spring element having a substantially double wishbone shape.

42. A prosthetic foot, comprising:

an upper plate;

a lower plate;

a compressible layer connected to the upper plate and the lower plate and separating the upper plate from the lower plate; and

an energy storing spring element made of resilient material embedded within the compressible layer and spaced apart from the upper and lower plates, said spring element comprising a plate-like member with a curvilinear concave downward shape.

43. A prosthetic foot including a resilient ankle block for separably mounting between a foot plate and an ankle plate of a prosthetic foot for providing resilient kinematic support to an amputee relative to a ground surface, the ankle block comprising a block of resilient material and at least one spring insert embedded within the block of resilient material, wherein a first spring insert comprises upper and lower substantially plate-like members joined at their center and separated at their ends, the upper member being substantially curvilinear concave upward and the lower member being substantially curvilinear concave downward.

44. The prosthetic foot of claim 43, wherein the first spring insert is made of a carbon fiber composite material.

45. The prosthetic foot of claim 43, wherein a second spring insert comprises at least one tubular stiffener.

46. The prosthetic foot of claim 45, wherein a first tubular stiffener is positioned in a fore region of the ankle block between the upper and lower substantially plate-like members, and a second tubular stiffener is positioned in an aft region of the ankle block between the upper and lower substantially plate-like members.

47. The prosthetic foot of claim 46, wherein the first and second tubular stiffeners are made of an expanded polyurethane having a density between about 150 and 1500 kg/m^3.

48. The prosthetic foot of claim 47, wherein the first and second tubular stiffeners are made of an expanded polyurethane having a density of between about 250 and 750 kg/m^3.

49. A prosthetic foot including a resilient ankle block for separably mounting between a foot plate and an ankle plate of a prosthetic foot for providing resilient kinematic support to an amputee relative to a ground surface, the ankle block comprising a block of resilient material and at least one energy storing spring insert embedded within the block of resilient material, wherein the at least one spring insert is a plate-like member having a substantially curvilinear downward shape.

50. A prosthetic foot, comprising:

a support plate made of a resilient material and having a length approximately equal to the length of a human foot;

a layer of compressible material mounted to the support plate; and

a spring element comprising at least one substantially plate-like member embedded within the layer of compressible material, said spring element being made of a carbon fiber material.

51. A prosthetic foot, comprising:

a support plate made of a resilient material and having a length approximately equal to the length of a human foot;

a layer of compressible material mounted to the support plate; and

a spring element comprising a pair of substantially plate-like members being secured at their center and separated at their ends, at least one of said plate-like members being embedded within the layer of compressible material.

52. A prosthetic foot, comprising:

a support plate made of a resilient material and having a length approximately equal to the length of a human foot;

a layer of compressible material mounted to the support plate; and

a spring element comprising at least one substantially plate-like member embedded within the layer of compressible material and having a curvilinear concave downward shape.

* * * * *

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United States Patent [19]

Wilkinson

[11] **Patent Number: 6,053,946**

[45] **Date of Patent: Apr. 25, 2000**

[54] **FLEXIBLE PROSTHETIC FOOT APPARATUS**

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[21] Appl. No.: **09/028,199**

[22] Filed: **Feb. 23, 1998**

[51] **Int. Cl.**[7] **A61F 2/66**

[52] **U.S. Cl.** **623/52**; 623/55

[58] **Field of Search** 623/47, 50, 52, 623/53, 55, 56

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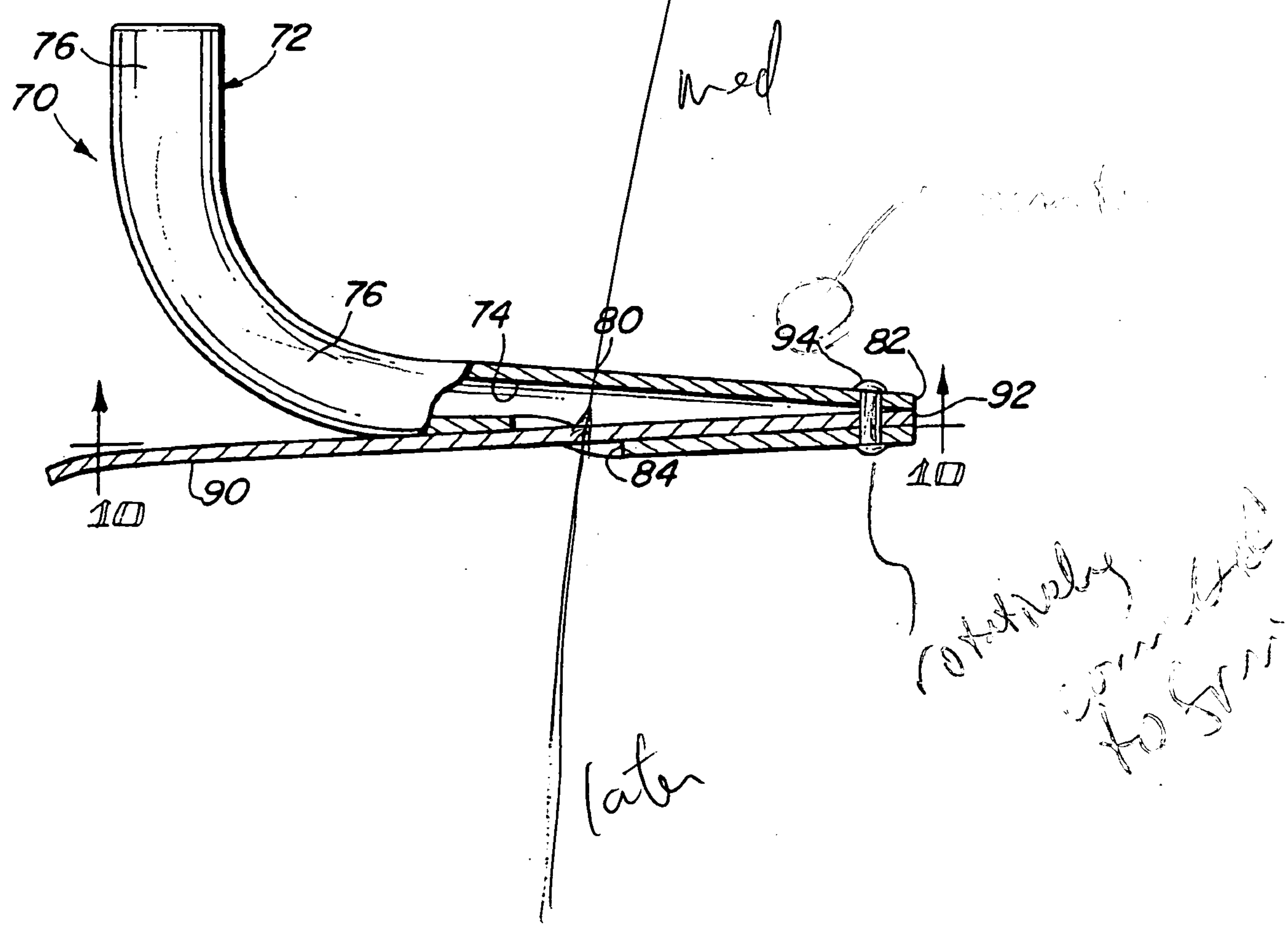
Primary Examiner—David H. Willse
Attorney, Agent, or Firm—H. Gordon Shields

[57] **ABSTRACT**

Prosthetic foot apparatus includes a tubular element appropriately bent and flattened to provide desired flexibility. The extent of flexibility, and accordingly the extent of the bending and flattening of the tubular element provides desired stiffness or flexibility according to the desired characteristic, complementary of the user of the apparatus. Different embodiments are shown, including an embodiment which includes a separate foot plate secured to and extending into the foot portion of the tubular element.

5 Claims, 1 Drawing Sheet



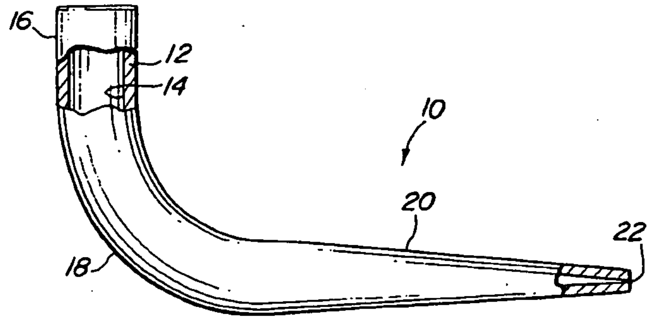


FIG. 1

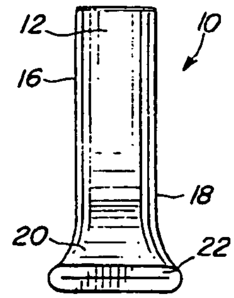


FIG. 2

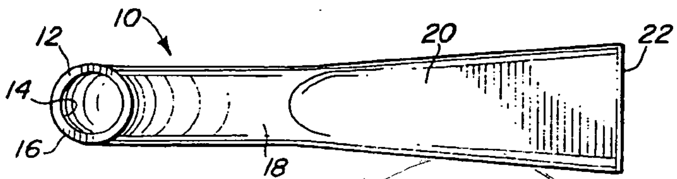


FIG. 3

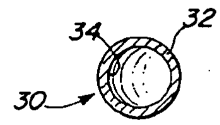


FIG. 5

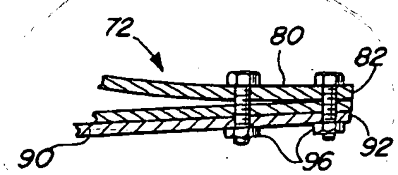


FIG. 11

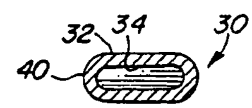


FIG. 6

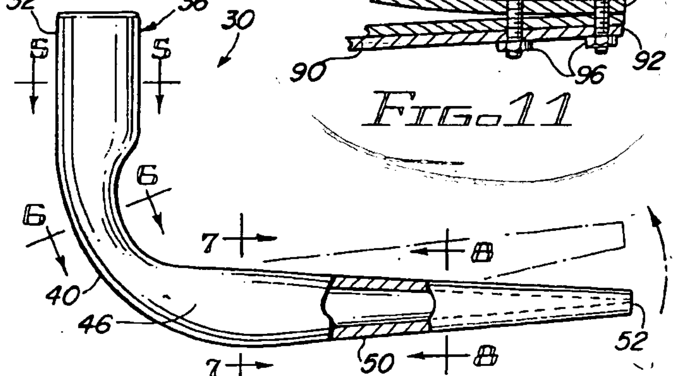


FIG. 4

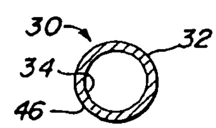


FIG. 7

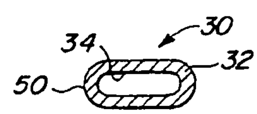


FIG. 8

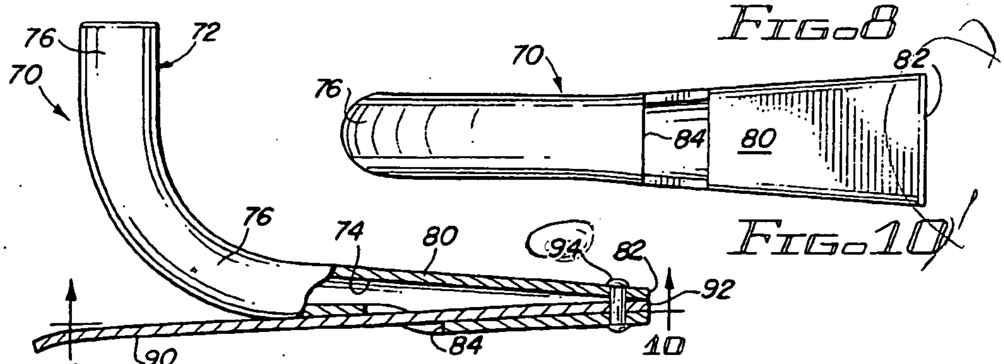


FIG. 10

FIG. 9

FLEXIBLE PROSTHETIC FOOT APPARATUS

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to prosthetic appliances and, more particularly, to a flexible prosthetic foot.

2. Description of the Prior Art

U.S. Pat. No. 4,547,913 (Phillips) relates to a composite prosthetic foot and leg which includes three portions, a leg portion, a foot portion, and a heel portion. The three portions are joined together rigidly. The three elements provide a degree of flexibility in response to ankle movements and foot movements, but provide sidewise rigidity. Various embodiments are disclosed.

U.S. Pat. No. 4,822,363 (Phillips) provides a different embodiment by the same inventor as the '913 patent, discussed above. The apparatus is made of laminated material to provide a prosthetic leg connected to a prosthetic foot. The leg portion is curved to define the foot, with a separate head portion connected to the foot portion. Various stiffness may be provided in the foot portion. Again different embodiments are disclosed.

U.S. Pat. No. 5,062,859 (Naeder) discloses a prosthetic foot which includes a resilient foot insert. The foot insert is of a general "Z" configuration. Different embodiments are illustrated.

U.S. Pat. No. 5,156,631 (Merlette) discloses a prosthetic foot and leg in which a leg element curves to define a foot element, and a separate segment is bonded to the forward extending foot portion extension of the leg element. The separate foot portion comprises or defines a sole element.

U.S. Pat. No. 5,258,039 (Goh et al) discloses a prosthetic foot apparatus made of resin impregnated woven fabric material. The apparatus is made of two segments both of which are curved to define a foot and heel portion and which provides the substantial degree of flexibility. Various embodiments or configurations are disclosed.

U.S. Pat. No. 5,376,140 (Ryan) discloses a prosthetic foot apparatus made of composite material. The apparatus has a general configuration of a natural foot with various elements involved, including a foamed polymer body, and cushioning material provides elasticity and flexion.

U.S. Pat. No. 5,486,209 (Phillips) discloses a prosthetic foot apparatus made of laminated materials. The apparatus includes an ankle portion, a foot portion, and a heel portion. Various configurations are illustrated.

U.S. Pat. No. 5,507,838 (Chen) discloses an artificial foot apparatus having a foot shaped casing and insert elements into the casing.

U.S. Pat. No. 5,549,714 (Phillips) discloses another prosthetic foot apparatus made of different elements secured together. Various elements are interchangeable to match the weight, stride, and activity schedule of the user of the apparatus.

U.S. Pat. No. 5,593,456 (Merlette) discloses another prosthetic leg and foot apparatus made of a single monolithic elongated composite member. The member includes a semi-flexible shank portion, an ankle portion, a fore-foot portion, and a toe portion. The apparatus is designed primarily for athletic type use.

U.S. Pat. No. 5,593,457 (Phillips) discloses apparatus similar to that disclosed in the above referred '290 patent. Both the '290 patent and the '457 patent are continuations of the same parent application.

SUMMARY OF THE INVENTION

The invention claims and described herein comprises a prosthetic foot made of a single tubular element which is flattened or configured to provide the degree of flexibility for the element. A second embodiment includes a flat plate appropriately secured to and extending inside of a foot portion of the tubular element.

Among the objects of the present invention are the following:

To provide new and useful prosthetic foot apparatus;

To provide new and useful prosthetic foot apparatus including a tubular element;

To provide new and useful prosthetic foot apparatus made of a tubular element and appropriately flattened or configured to provide a desired degree of flexibility;

To provide new and useful prosthetic foot apparatus including a flat plate secured to a tubular element; and

To provide new and useful prosthetic foot apparatus having a flat plate element secured to and extending into the interior of a foot portion of a tubular element.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a side view in partial section of the apparatus of the present invention.

FIG. 2 is a front view of the apparatus of FIG. 1.

FIG. 3 is a top view of the apparatus of FIGS. 1 and 2.

FIG. 4 is a side view of an alternate embodiment of the apparatus of FIGS. 1, 2, and 3.

FIG. 5 is a view in partial section taken generally along line 5—5 of FIG. 4.

FIG. 6 is a view in partial section taken generally along line 6—6 of FIG. 4.

FIG. 7 is a view in partial section taken generally along line 7—7 of FIG. 4.

FIG. 8 is a view in partial section taken generally along line 8—8 of FIG. 4.

FIG. 9 is a view in partial section of an alternate embodiment of the apparatus of the present invention.

FIG. 10 is a view in partial section taken generally along line 10—10 of FIG. 9.

FIG. 11 is a view in partial section of an alternate embodiment of FIGS. 9 and 10.

DESCRIPTION OF THE PREFERRED EMBODIMENT

FIG. 1 is a side view of flexible prosthetic foot apparatus 10 of the present invention. FIG. 2 is a front view of the foot apparatus 10 of FIG. 1. FIG. 3 is a top view of the flexible foot apparatus 10 of FIGS. 1 and 2. For the following discussion, reference will be made to FIGS. 1, 2, and 3.

The flexible foot apparatus 10 comprises a tubular element 12 in which there is a bore 14. The foot apparatus 10 may be divided into three portions, an upper, straight portion 16, a curved, ankle portion 18, and a tapering lower portion 20. The lower portion tapers to a toe end 22 in which the tube 18 is substantially flat. The flattening of the tube 12 in the lower foot portion 20 results in an outward tapering of the lower foot portion 20, outwardly from the curved portion 18 to the end 22. This is best shown in FIG. 3.

In the side view of FIG. 1, the gradual tapering of the tube 12 from the upper straight or full diameter portion 16, through the curved portion 18, onto the foot portion 20, and

terminating in the toe end 22 is shown. The degree or extent of flexing varies according to the degree or extent of the flattening of the tube. In the embodiment of FIGS. 1–3, there will be some flexing in the curved portion 18, as an ankle flexing, but even more in the foot portion 20 and in the toe area 22.

FIG. 4 is a side view, partially broken away, of an alternate embodiment 30 of the apparatus 10 in FIGS. 1, 2, and 3. FIG. 5 is a view in partial section of the apparatus 30 taken generally along line 5—5 of FIG. 4. FIG. 6 is a view in partial section taken generally along line 6—6 of FIG. 4, while FIG. 7 is a view in partial section taken generally along line 7—7 of FIG. 4, and FIG. 8 is a view in partial section taken generally along line 8—8 of FIG. 4. For the following discussion, reference will be made to FIGS. 4, 5, 6, 7, and 8.

The flexible foot apparatus 30 is made of a tube 32 which has an interior bore 34. The flexible foot apparatus 30 includes a relatively straight upper portion 36, which corresponds to the upper portion 16 of the apparatus 10. The tubular member 32 includes a bore 34. The tubular member 32 is generally circular, and accordingly the bore 34 is generally circular.

Downwardly from the upper, straight portion 36 is a partially flattened or necked down curved portion 40. The portion 40 corresponds to an ankle portion of a natural leg in that there is flexing to a degree permitted in the area 40 by the flattening or necking down of the tube 32. The general flattening of the tube 32 in the area 40 is illustrated in detail in FIG. 6.

Downwardly from the neck down or flattened portion 40 is another circular or full cross-sectional area 46. In the area 46, the tubular member 30 is at a full diameter cross-sectional configuration, as illustrated in FIG. 7.

From the lower circular portion 46, the tubular member 32 tapers to an outer end 52. The tapering portion 50 is similar to the tapering front foot portion 20 of the apparatus 10. The tapering is accomplished by a gradual flattening of the tube 32 until the tubular member 32 is flattened to terminate at the end 52. The end 52, in an end view, is substantial the same as that illustrated in FIG. 2 for the end 22 of the tubular member 12.

In dash/dot line in FIG. 4, the flexing of the "ankle" portion 40 is illustrated. The dash/dot arrow adjacent to the tip 52 illustrates the relative movement of the foot tapering portion 50 relative to the upper straight portion 36. Again, the flexing is permitted or allowed by the necking down, or semi flattening of the tube 32 in the area 40, as illustrated in FIG. 6.

By varying the cross section of the tubular member 32 in the "ankle" portion 40, the flexing of the apparatus is varied. The greater the extent of the flattening or necking down, the greater the degree of flexing, and vice versa. Thus, in addition to the flexing of the portion 40, there will also be some flexing in the bottom foot portion 50 due to the flattening of the tubular member 32. This latter flexing provides a degree of springiness to the apparatus 30.

FIG. 9 comprises a side view in partial section of an alternate embodiment 70 of the apparatus of the present invention. The apparatus 70 is another alternate embodiment of the apparatus 10 of FIGS. 1, 2, and 3. FIG. 10 is a bottom view taken generally along ling 10—10 of FIG. 9. For the following discussion, reference will be made primarily to FIGS. 9 and 10.

The flexible prosthetic foot apparatus 70 is again made of a tubular member 72 which has a bore 74. The apparatus 70 includes an upper portion 76 which is generally straight, and accordingly the cross-sectional configuration of the tubular member 70 will be circular, such as illustrated in FIGS. 3, 5, and 7, for the apparatus 10 and 30. The straight upper portion 76 then curves to define a portion 76, which may be considered as an ankle portion. From the curved portion 76, the tubular member 72 is tapered inwardly and flattened and terminates in a front end or toe tip 82. The continual tapering of the flattening of the tubular member 72 from the upper straight portion 76 to the toe tip 82 may be understood from FIG. 9.

On the bottom of the tubular member 76, at the tapering foot portion 80, there is a slot 84. The front end of a plate 90 extends through the slot 84 and extends to the tip 82 where the plate terminates in an end 92. An appropriate fastener 94, such as a rivet, may be used to secure the plate 90 to the foot portion 80, if desired or if required. However, as shown in FIG. 9, and as also may be understood from FIG. 2 and from FIGS. 1 and 4, the end or tip 82 of the tubular member 76 is flattened so that the plate 90 is held relatively securely therein. Thus, at the front end of the foot portion 80, the tips 92 of the plate 90 and 82 of the tube 72 are flattened adjacent to each other.

The flattening of the tube 72 in the foot area 80, resulting from the inward taper of the tube 72, results in an outward taper of the portion 80, as best illustrated in FIG. 10.

FIG. 11 is a fragmentary view in partial section of an alternate embodiment of the apparatus 70 from that illustrated in FIG. 9. Instead of having the plate 90 extend through the slot 84 and into the interior bore 74 of the tubular member 72 at the foot portion 80, the plate 92 is simply appropriately secured to the bottom of the foot portion 80 by a pair of appropriate fasteners 96, such as nuts and bolts. This eliminates the need for the slot 84.

Three embodiments of a flexible prosthetic foot are illustrated and have been discussed. They all share in construction in that a tubular member is used to form the vertical portion of the foot and which is appropriately connected to a leg member or other prosthesis, not shown, but as is well known and understood. The tubular member curves to define an ankle portion between the vertical portion and a foot portion. Deformation of the ankle portion provides flexibility to create to a degree the desired movement. Flexing of the tubular member varies according to the flattening or deformation in the cross sectional configuration, as discussed above. The greater the extent of flattening of the tubular member, the greater the degree or extent of the flexibility.

While the principles of the invention have been made clear in illustrative embodiments, there will be immediately obvious to those skilled in the art many modifications of structure, arrangement, proportions, the elements, materials, and components used in the practice of the invention, and otherwise, which are particularly adapted to specific environments and operative requirements without departing from those principles. The appended claims are intended to cover and embrace any and all such modifications, within the limits only of the true spirit and scope of the invention.

What I claim is:

1. Prosthetic foot apparatus comprising in combination:

a resilient tubular prosthetic support element including
  a relatively straight upper tubular portion,
  a curved middle tubular portion,
  a lower tubular portion terminating in a relatively flattened end; and

the curved middle tubular portion is flattened to allow flexing of the tubular element.

2. The apparatus of claim 1 which further includes a plate secured to the lower tubular portion.

3. The apparatus of claim 2 in which the lower tubular portion includes a slot and the plate extends into the slot to secure the plate to the lower tubular portion.

4. The apparatus of claim 1 in which the flattening of the curved middle tubular portion is tapered to the lower tubular portion.

5. The apparatus of claim 4 in which the flattening of the curved middle tubular portion tapers on to the lower tubular portion.

* * * * *

US005800568A

United States Patent [19]

Atkinson et al.

[11] **Patent Number: 5,800,568**

[45] **Date of Patent: Sep. 1, 1998**

[54] **PROSTHETIC ANKLE AND WALKING SYSTEM**

[75] Inventors: **Stewart L. Atkinson; Donald L. Poggi**, both of Bainbridge Island, Wash.

[73] Assignee: **Model & Instrument Development Corporation**, Poulsbo, Wash.

[21] Appl. No.: **602,241**

[22] Filed: **Feb. 16, 1996**

[51] **Int. Cl.**[6] **A61F 2/66**

[52] **U.S. Cl.** **623/52; 623/55**

[58] **Field of Search** 623/47, 50–53, 623/54, 55

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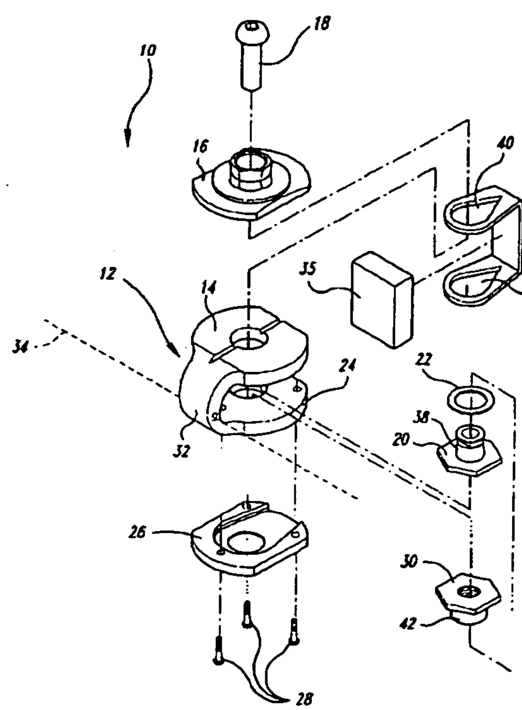
Primary Examiner—David H. Willse
Attorney, Agent, or Firm—Seed and Berry LLP

[57] **ABSTRACT**

An inventive prosthetic ankle for use between a pylon and a prosthetic foot to support a person's weight on the ground comprises an integrally formed, generally C-shaped carbon-fiber composite flexure member having upper, lower and curved legs. The upper leg is connected to a lower end of the pylon, and the lower leg is connected to an upper surface of the prosthetic foot. The curved leg interconnects the upper and lower legs, with the curved leg extending from a forward edge of the upper leg to a forward edge of the lower leg in a rearwardly-facing arc about a medial/lateral axis positioned forward of the pylon. The curved leg is dog-boned to facilitate canting of the pylon with respect to the prosthetic foot in the medial/lateral plane. Also, the curved leg is resilient to resiliently bias the upper and lower legs apart from one another so the legs are positioned in a spaced-apart relationship with respect to one another when the person's weight is off the prosthetic ankle. The resilient biasing also allows the upper and lower legs to pivot toward one another about the medial/lateral axis when the person's weight is on the prosthetic ankle at heel strike. As a result, the prosthetic foot falls flat on the ground soon after heel strike. A limit strap coupled between the upper and lower legs limits rotation of the upper and lower legs away from each other about the medial/lateral axis so the flexure characteristics experienced by an amputee during step-off are substantially determined by the flexure characteristics of the toe portion of the prosthetic foot.

1 Claim, 7 Drawing Sheets



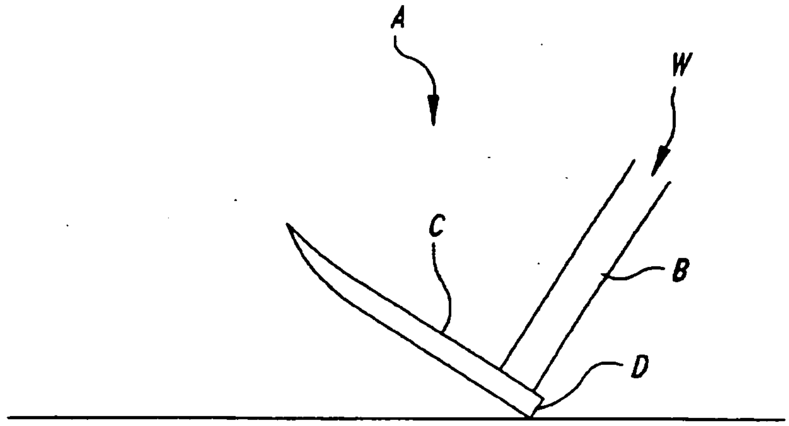


Fig. 1
(PRIOR ART)

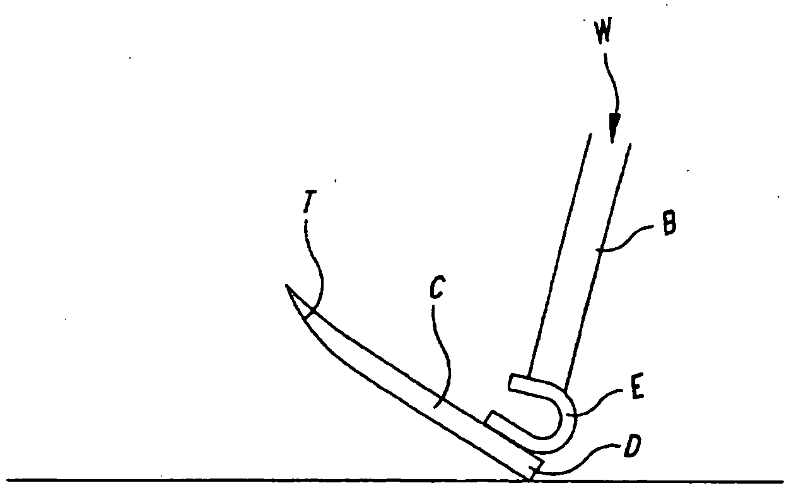


Fig. 2
(PRIOR ART)

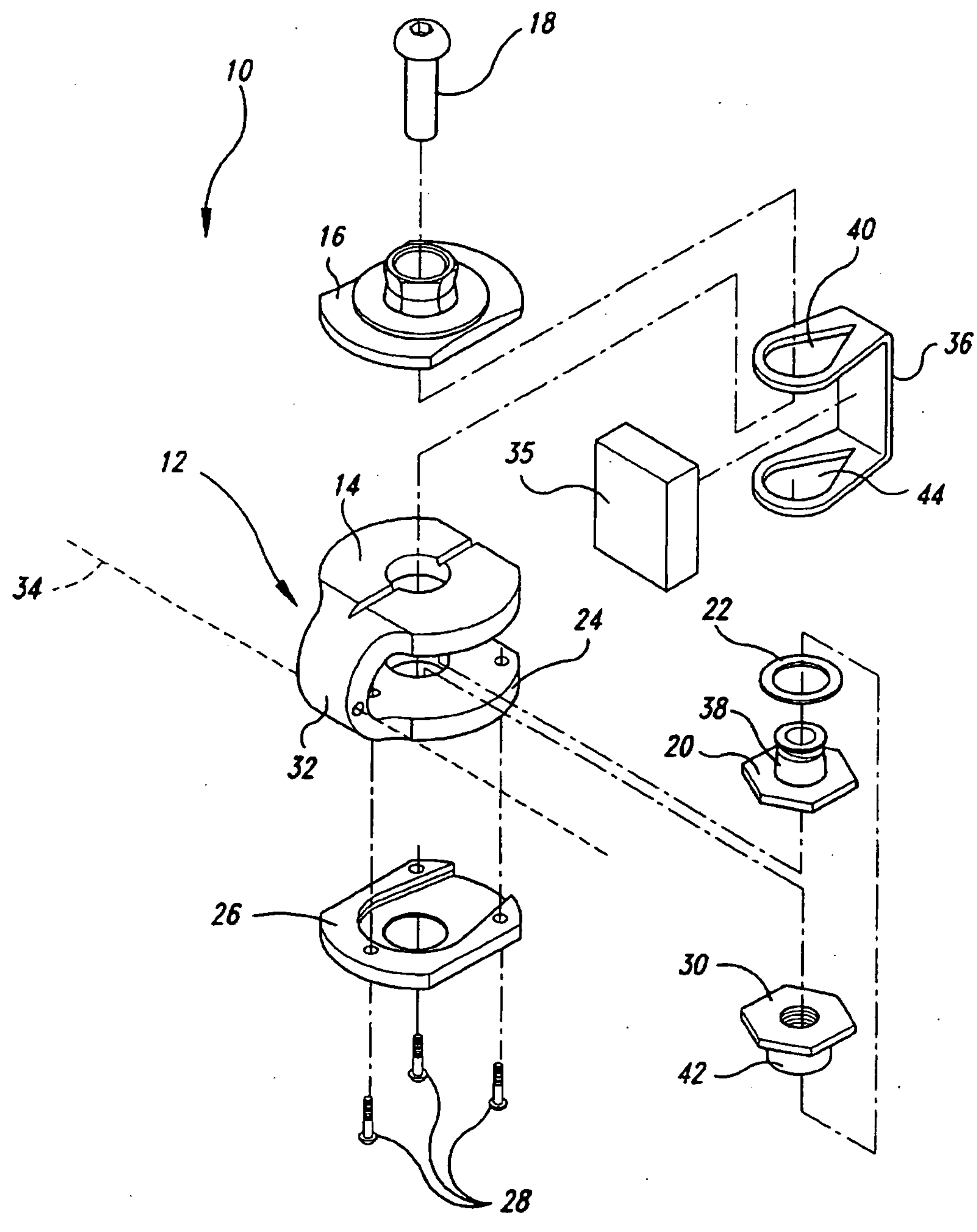


Fig. 3

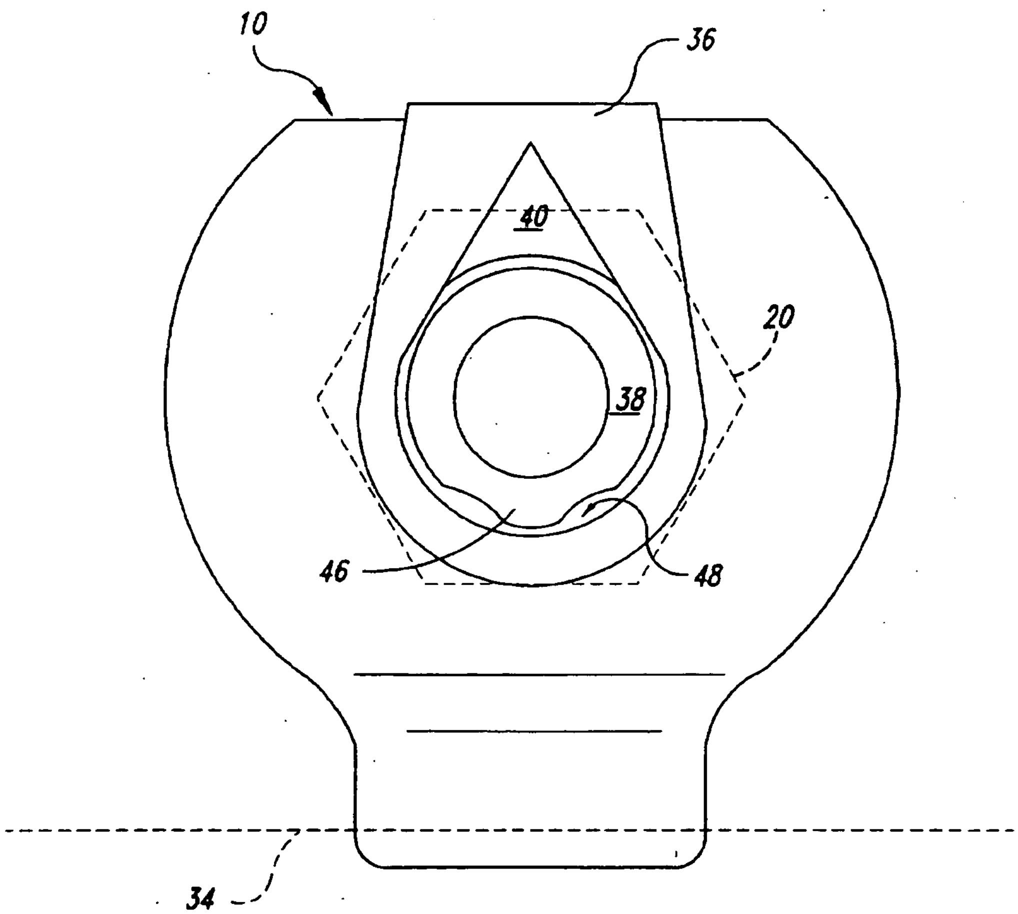


Fig. 4

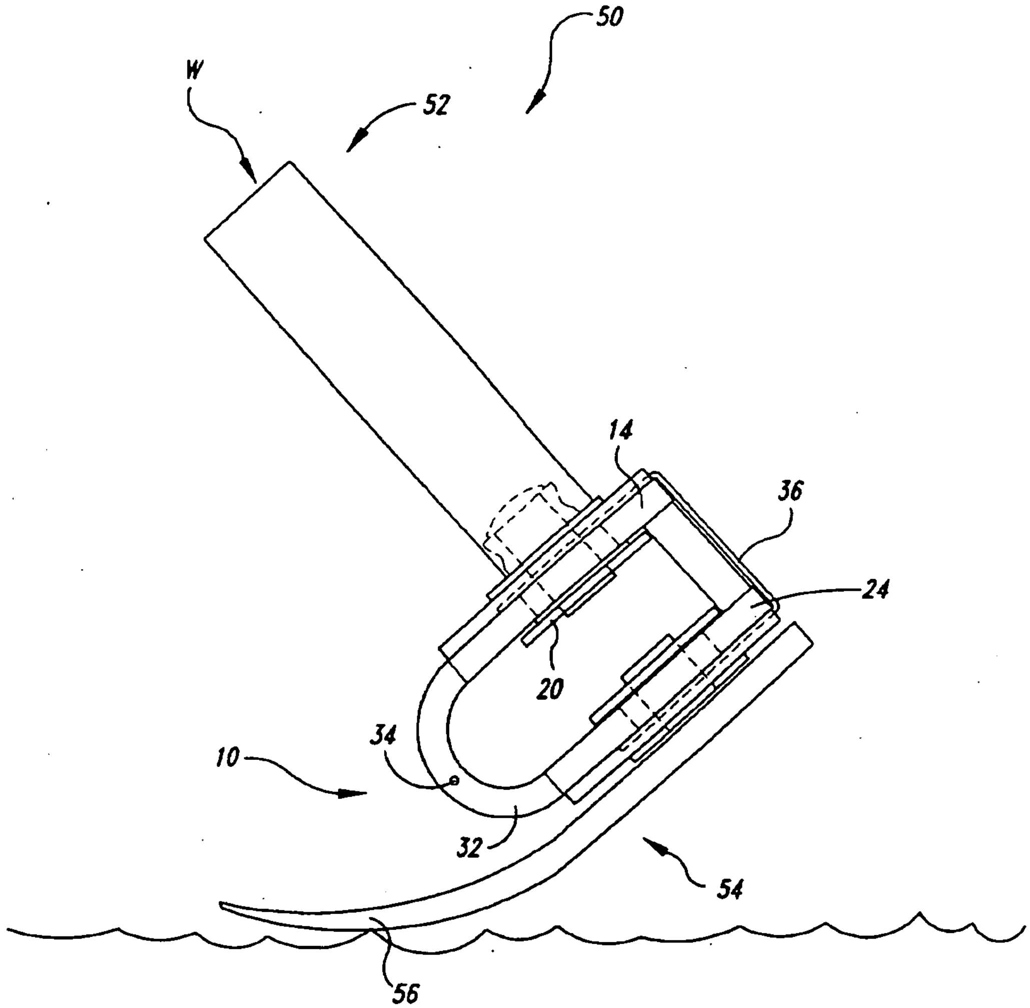


Fig. 5A

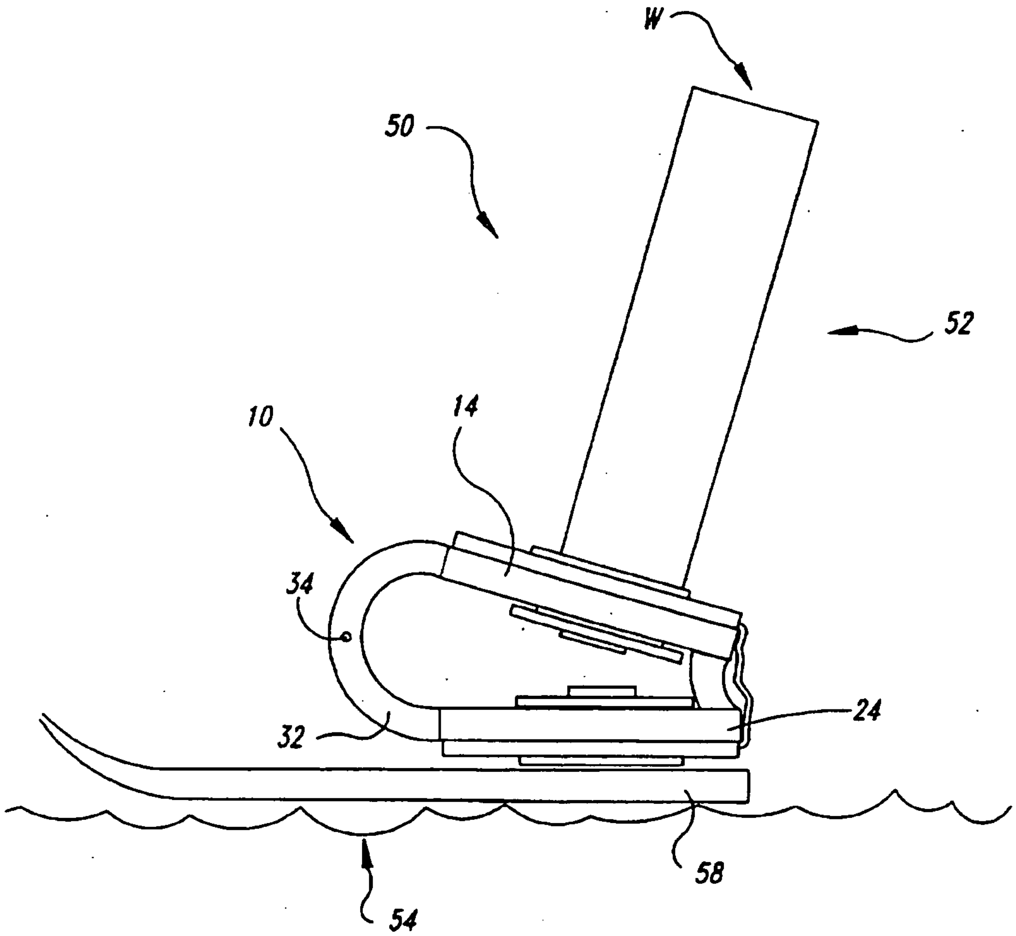


Fig. 5B

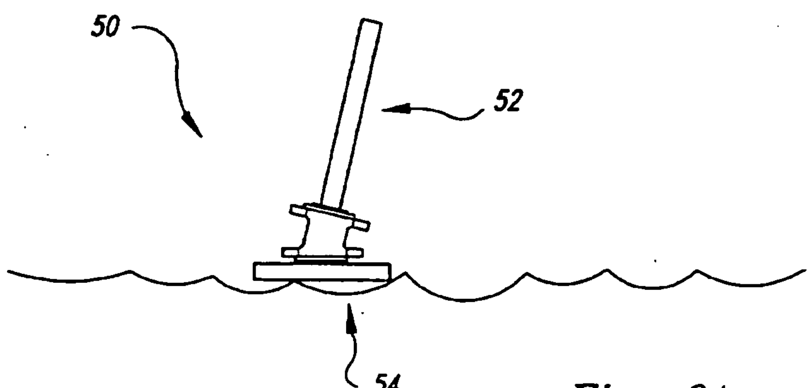


Fig. 6A

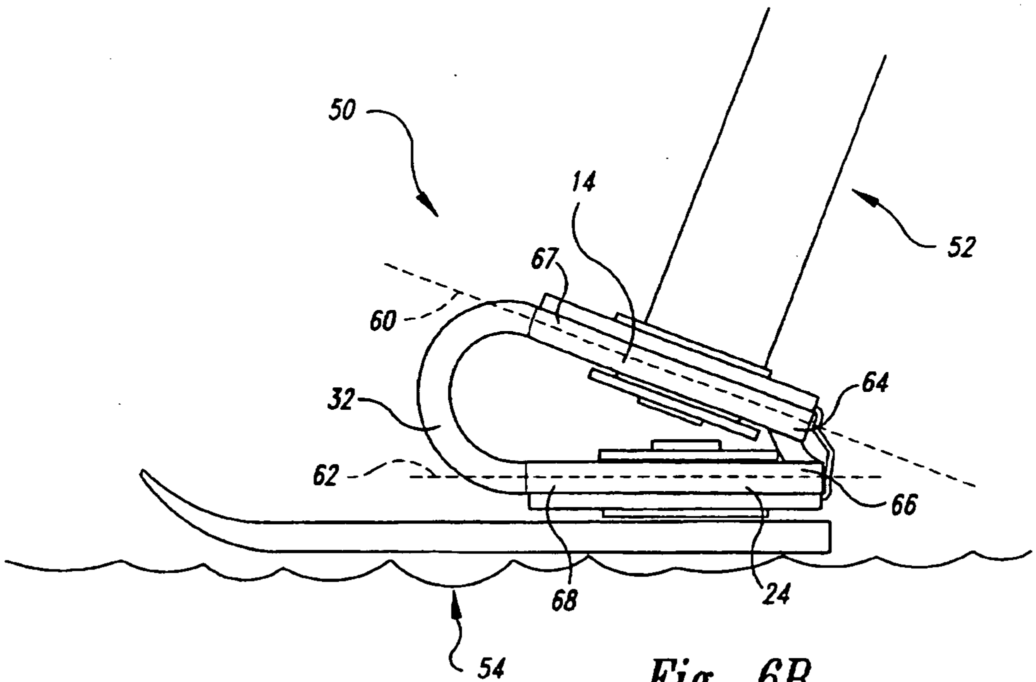


Fig. 6B

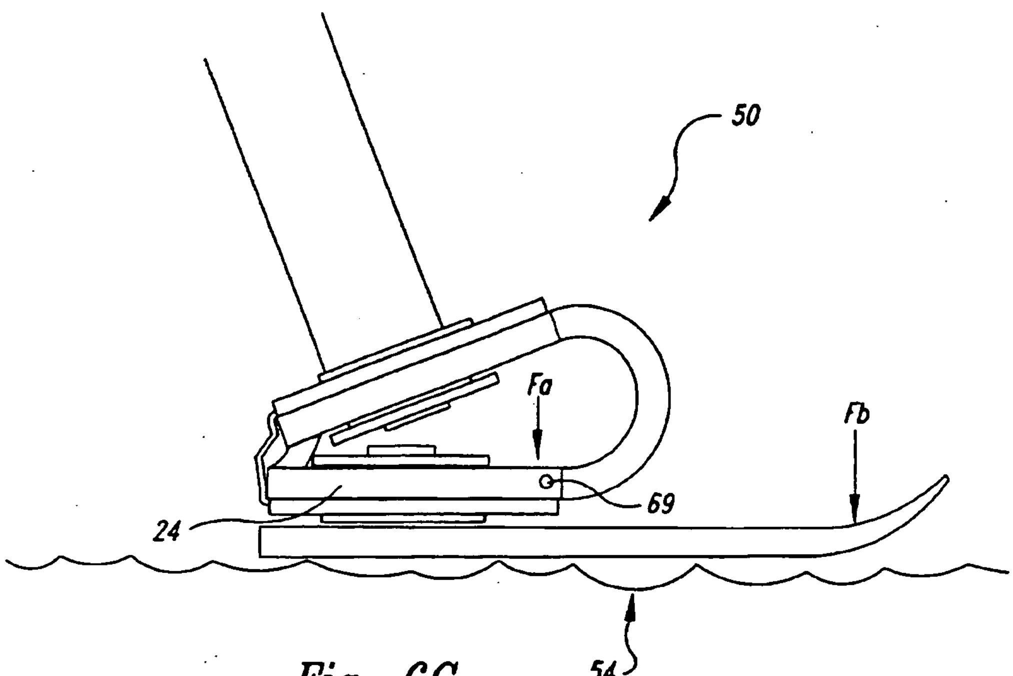


Fig. 6C

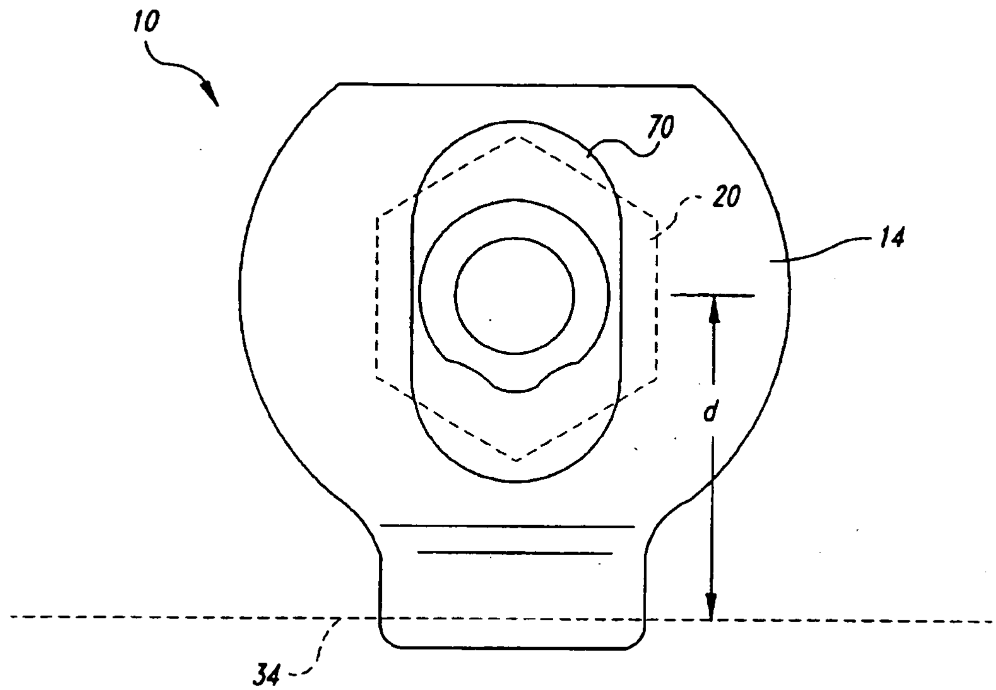


Fig. 7A

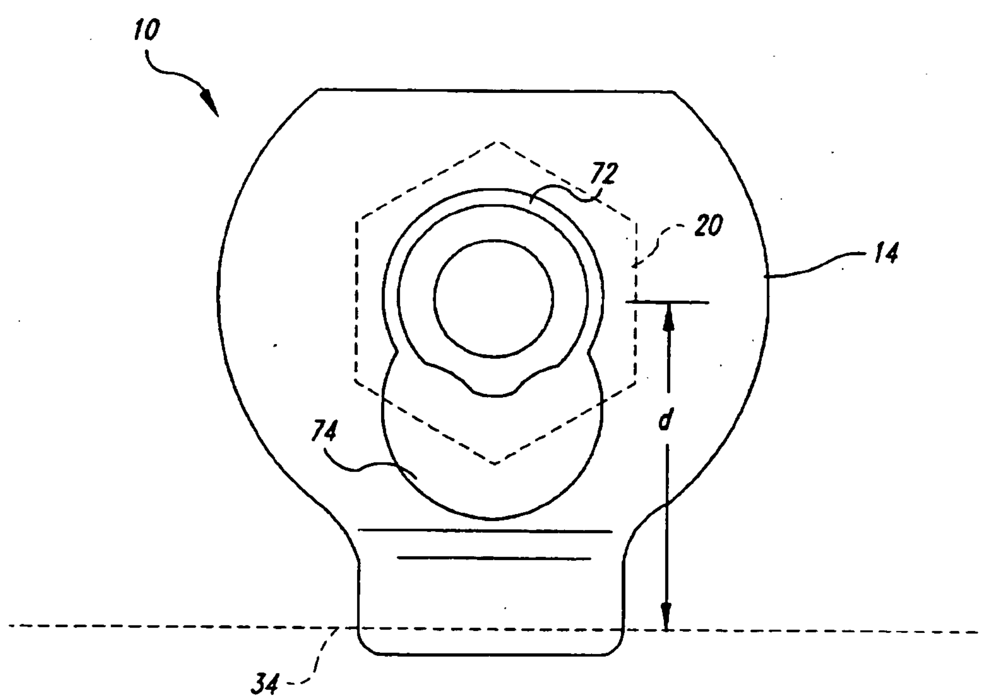


Fig. 7B

PROSTHETIC ANKLE AND WALKING SYSTEM

FIELD OF THE INVENTION

This invention relates in general to prosthetic devices, and in particular to prosthetic ankles.

BACKGROUND OF THE INVENTION

As shown in FIG. 1, leg amputees often regain significant walking capability by using a walking system A including a pylon B rigidly connected to a prosthetic foot C. Unfortunately, many of these amputees experience instability while walking. One reason for this is that the prosthetic foot C is not flat on the ground at heel strike, and does not fall flat until just prior to lift off when the amputee's weight W is coming off the prosthetic foot C. Prior to that time, the amputee's weight W is largely supported by the heel D of the prosthetic foot C. Many amputees also find these rigid walking systems uncomfortable because of a lack of cushioning at heel strike.

As shown in FIG. 2, prosthetists have attempted to alleviate the uncomfortable nature of rigid walking systems by inserting a resilient ankle E between the pylon B and the prosthetic foot C. Unfortunately, this has exacerbated the instability problem. The inventors have determined that the amputee's weight W at heel strike causes the toe T of the prosthetic foot C to pivot upward toward the pylon B rather than downward to the ground. As a result, the prosthetic foot C fails to fall flat for an even longer portion of the amputee's gait than with rigid walking systems.

Therefore, there is a need in the art for a walking system that places prosthetic feet flat on the ground at an earlier time during a step to provide amputees with improved stability.

SUMMARY OF THE INVENTION

An inventive walking system includes a prosthetic ankle comprising an upper leg connected to a lower end of a pylon and a lower leg connected to an upper surface of a prosthetic foot. An interconnecting member interconnects the upper and lower legs so the legs rotate about a medial/lateral axis positioned forward of the pylon. The interconnecting member resiliently biases the legs apart from one another so the legs are positioned in a spaced-apart relationship with respect to one another when the person's weight is off the prosthetic ankle. Also, the legs rotate toward one another about the medial/lateral axis when the person's weight is placed on the prosthetic ankle at heel strike, thereby allowing a toe of the prosthetic foot to rotate toward the ground at heel strike. As a result, the prosthetic foot falls flat on the ground soon after its heel strikes the ground. The inventive walking system thus provides improved stability.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a side elevational view of a prior art walking system.

FIG. 2 is a side elevational view of the prior art walking system of FIG. 1 with a prior art resilient ankle between the pylon and prosthetic foot.

FIG. 3 is an exploded isometric view of a prosthetic ankle according to the present invention.

FIG. 4 is top plan view of the preferred prosthetic ankle of FIG. 3.

FIGS. 5A and 5B are side elevational views of a walking system including the preferred prosthetic ankle of FIG. 3.

FIGS. 6A, 6B and 6C are front and side elevational views of the prosthetic ankle of FIG. 3.

FIGS. 7A and 7B are top plan views of alternative versions of the prosthetic ankle of FIG. 3.

DETAILED DESCRIPTION OF THE INVENTION

A preferred prosthetic ankle 10 shown in FIG. 3 includes a generally C-shaped carbon-fiber composite flexure member 12 having an upper leg 14 connected to a conventional upper attachment plate 16 with a bolt 18. The bolt 18 extends through a hole in the upper attachment plate 16 and into an upper insert nut 20 inserted into a hole in the flexure member's upper leg 14. A lock washer 22 prevents the upper insert nut 20 from turning when the bolt 18 is tight. The upper attachment plate 16 is connectable to a lower end of a conventional pylon (not shown) in a known manner. Although the present invention will be described with respect to a carbon-fiber composite flexure member, a variety of other materials will also work for purposes of this invention. For example, steel, plastic, DELRIN®, nylon and aluminum will work.

A lower leg 24 of the flexure member 12 is connected to a conventional lower attachment plate 26 with conventional fasteners, such as screws 28. The lower attachment plate 26 is connectable to an upper surface of a conventional prosthetic foot (not shown) with a bolt (not shown) extending from the prosthetic foot (not shown), through a hole in the lower attachment plate 26, and into a lower insert nut 30 inserted into a hole in the flexure member's lower leg 24. Of course, a wide variety of other mechanisms can be used to attach the prosthetic ankle 10 to a prosthetic foot, or the prosthetic ankle 10 can be integral with the prosthetic foot.

A curved leg 32 of the flexure member 12 is integral with and interconnects the flexure member's upper leg 14 and lower leg 24. The flexure member's curved leg 32 resiliently biases the flexure member's upper and lower legs 14 and 24 with respect to one another about a medial/lateral axis 34. As a result, the upper and lower legs 14 and 24 are positioned in a parallel, spaced-apart relationship when an amputee's weight is not loading the prosthetic ankle 10. Of course, other mechanisms will work as well to provide a pivotal connection between the upper and lower legs 14 and 24.

The flexure member's curved leg 32 preferably assists in making the prosthetic ankle 10 more or less rigid at toe-off. This allows the toe-off flexure characteristics experienced by an amputee using the prosthetic ankle 10 to be substantially determined by the toe portion of a prosthetic foot (not shown) attached to the prosthetic ankle, as will be described in more detail below. The prosthetic ankle 10 can do this by, for example, having a curved leg 32 constructed with the angle of the carbon fibers in the curved leg 32 varying from being parallel with the upper and lower legs 14 and 24 at the inside surface of the curved leg 32 to being perpendicular with the upper and lower legs 14 and 24 at the outside surface of the curved leg 32. This allows the flexure member's curved leg 32 to rigidly resist rotation of the flexure member's upper and lower legs 14 and 24 away from one another about the medial/lateral axis 34 past their low-load parallel position. Of course, a wide variety of other well-known carbon-fiber composite construction techniques will also work for this purpose.

Preferably, the flexure member's curved leg 32 is cut into a shape somewhat resembling a dog's bone. This 'dog-boning' helps the curved leg 32 twist more easily and allows a pylon (not shown) attached to the upper attachment plate

16 to more easily cant in the medial/lateral plane with respect to a prosthetic foot (not shown) attached to the lower attachment plate 26. The dog-boning also allows the pylon (not shown) to twist about its longitudinal axis in axial torsion with respect to the prosthetic foot (not shown). The shape, length and depth of the dog-boning can be adjusted to optimize the canting in the medial/lateral plane for a particular amputee. For example, the dog-boning on the medial side can be made deeper than the dog-boning on the lateral side so canting in the medial direction is easier than canting in the lateral direction. Also, the dog-boning can be adjusted to optimize the ability of the flexure member 12 to allow the described axial torsion. In particular, an active person, such as a golfer, might wish to optimize the axial torsion capability of the flexure member 12 so they can perform activities, such as a golf swing, which require significant axial torsion.

A resilient bias element, such as a cushion 35, can be positioned between the flexure member's upper and lower legs 14 and 24 to assist the curved leg 32 in resiliently biasing the upper and lower legs 14 and 24 with respect to each other. Of course, a wide variety of other resilient bias elements, such as air bladders, liquid bladders, and springs, will work for purposes of this invention.

A limit strap 36 brackets and couples the flexure member's upper and lower legs 14 and 24, with a shaft 38 of the upper insert nut 20 extending through an upper hole 40 in the limit strap 36 and a shaft 42 of the lower insert nut 30 extending through a lower hole 44 in the limit strap 36. The limit strap 36 assists the flexure member's curved leg 32 in rigidly limiting rotation of the flexure member's upper and lower legs 14 and 24 away from one another about the medial/lateral axis 34, and it is preferably made with non-resilient flexile Kevlar®. Of course, other flexile materials, such as nylon or a phenolic fiber material, and resilient flexile materials will also work for purposes of this invention.

The limit strap 36 is shown in more detail in a top plan view of the prosthetic ankle 10 in FIG. 4. Turning the upper insert nut 20 causes a cam lobe 46 on the upper insert nut's shaft 38 to press against an interior edge 48 of the limit strap 36 and thereby tension the limit strap 36. As a result, the limit strap 36 further limits rotation of the flexure member's upper leg 14 away from the flexure member's lower leg (FIG. 3) about the medial/lateral axis 34.

As shown in FIG. 5A, in operation the prosthetic ankle 10 can be part of a walking system 50 including a conventional pylon 52 positioned rearwardly from the medial/lateral axis 34 and a conventional prosthetic foot 54. When the amputee is stepping off a toe portion 56 of the prosthetic foot 54 and most of the amputee's weight W is not loading the prosthetic ankle 10, the resilient curved leg 32 urges the flexure member's upper and lower legs 14 and 24 to rotate away from one another to their low-load parallel position described above.

When the flexure member's upper and lower legs 14 and 24 are at their low-load parallel position, the curved leg 32 and the limit strap 36 together rigidly limit further rotation of the upper leg 14 away from the lower leg 24 to a degree determined by the curved leg's construction and the limit strap's tension, as described above. Thus, if the upper insert nut 20 causes the limit strap 36 to be in high tension, then the flexure characteristics of the walking system 50 at toe-off are almost entirely determined by the flexure characteristics of the prosthetic foot's toe portion 56 because the prosthetic ankle 10 is substantially rigid at toe-off. If, instead, the limit

strap 36 is in low tension, then the flexure characteristics of the walking system 50 at toe-off are to a greater degree determined by the flexure characteristics of the prosthetic ankle 10 because the prosthetic ankle 10 is less rigid at toe-off. This allows an amputee to conveniently adjust the flexure characteristics of the walking system 50 at toe-off for different activities such as walking, running and skiing. Of course, the limit strap 36 will also work for this purpose if the prosthetic ankle 10 opens forwardly with the pylon 52 positioned forwardly from the medial/lateral pivot axis 34.

As shown in FIG. 5B, when the amputee's weight W is on the prosthetic ankle 10 and the prosthetic foot's heel 58 strikes the ground, the flexure member's curved leg 32 allows the flexure member's upper and lower legs 14 and 24 to rotate toward each other about the medial/lateral axis 34. This allows the prosthetic foot 54 to quickly fall flat on the ground when its heel 58 strikes the ground so the amputee's weight W is supported by the entire prosthetic foot 54 for most of the amputee's gait. As a result, the walking system 50 has improved stability.

As shown in FIGS. 6A–6C, the walking system 50 also has improved stability when the prosthetic foot 54 is flat on the ground during an amputee's stride and the amputee changes direction by moving the prosthetic foot 54 in a medial or lateral direction. For example, in a front elevational view shown in FIG. 6A, an amputee's right prosthetic foot 54 is flat on the ground and the amputee moves to the amputee's left, so the pylon 52 cants in the medial direction with respect to the prosthetic foot 54. As shown in a medial side elevational view in FIG. 6B, because the pylon 52 cants in the medial direction, a twist is introduced into the upper and lower legs 14 and 24 about anterior/posterior axes 60 and 62, respectively, of the upper and lower legs 14 and 24. Because the medial posterior portions 64 and 66 of the upper and lower legs, respectively, are farther from the curved leg 32 than the medial anterior portions 67 and 68, respectively, the medial posterior portion 64 of the upper leg 14 twists downward more than the medial anterior portion 67, and the medial posterior portion 66 of the lower leg 24 twists upward more than the medial anterior portion 68. As a result, the lateral anterior portion 69 of the lower leg 24, as shown in a lateral side elevational view in FIG. 6C, is forced to twist downward with a force F_a. Because the lower leg 24 is connected to the prosthetic foot 54, the downward force F_a on the lateral anterior portion 69 of the lower leg 24 causes a corresponding downward force F_b on the lateral toes of the prosthetic foot 54. As a result, the prosthetic foot 54 "digs in" and thus is more stable when the amputee moves in the medial direction. Of course, the prosthetic foot 54 also "digs in" as necessary if the amputee moves in the lateral direction, or if the prosthetic foot 54 is the amputee's left foot.

In an alternative version of the prosthetic ankle 10 shown in a top plan view in FIG. 7A, the upper insert nut 20 is inserted into a slotted hole 70 in the upper leg 14. This allows an amputee to conveniently adjust the torque arm distance d between the medial/lateral pivot axis 34 and the axes of the upper insert nut 20 and the pylon 52 (FIG. 5A). This ability to adjust the torque arm distance d allows the amputee to adjust the flexure characteristics of the prosthetic ankle 10 to suit his or her needs. Similarly, in another alternative version of the prosthetic ankle 10 shown in FIG. 7B, the upper insert nut 20 is inserted into a hole 72 in the upper leg 14 which is one of several holes 72 and 74. By selecting one of the several holes 72 and 74 for the upper insert nut 20, the amputee can adjust the torque arm distance d between the medial/lateral pivot axis 34 and the axes of the

upper insert nut 20 and the pylon 52 (FIG. 5A). Thus, the user can conveniently adjust the flexure characteristics of the prosthetic ankle 10 to suit his or her needs. Although the holes 72 and 74 are shown in FIG. 7B as being partially joined, they could of course be separated by a portion of the upper leg 14.

Although the present invention has been described with reference to a preferred embodiment, the invention is not limited to this preferred embodiment. Rather, the invention is limited only by the appended claims, which include within their scope all equivalent devices or methods which operate according to the principles of the invention as described.

We claim:

1. A prosthetic ankle for use between a pylon and a prosthetic foot to support a person's weight on the ground, the prosthetic ankle comprising:

an upper leg adapted for connecting to a lower end of the pylon, the upper leg having a hole through it in substantial alignment with a longitudinal axis of the pylon;

a lower leg adapted for connecting to the upper surface of the prosthetic foot in a manner in which the lower leg is substantially prevented from moving upwardly and downwardly with respect to the prosthetic foot;

an interconnecting member interconnecting the upper and lower legs so the legs rotate about a medial/lateral axis,

the interconnecting member resiliently biasing the legs apart from one another about the medial/lateral axis to space front portions of the upper and lower legs apart from one another by a greater distance than rear portions of the upper and lower legs when the person's weight is placed on the prosthetic ankle at heel strike; and

a limit device having a limit strap coupling the upper and lower legs to each other and a tensioning device coupled between the limit strap and one of the upper and lower legs, wherein the limit strap has a loop having an axis positioned in substantial axial alignment with the hole of the upper leg, wherein the tensioning device comprises a cylindrical insert nut inserted into the hole of the upper leg with its axis substantially coinciding with the hole of the upper leg and with an end extending through the loop of the limit strap, and wherein the insert nut has a cam lobe on its cylindrical surface pressing against an inside edge of the loop of the limit strap such that the limit strap may be tensioned to greater and lesser degrees by turning the insert nut.

* * * * *

US005116384A

United States Patent [19]

Wilson et al.

[11] **Patent Number: 5,116,384**

[45] **Date of Patent: May 26, 1992**

[54] **PROSTHETIC FOOT**

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[73] Assignee: **Syncor, Ltd.**, Abrams, Wis.

[21] Appl. No.: **576,228**

[22] Filed: **Aug. 31, 1990**

[51] **Int. Cl.**[5] **A61F 2/66**

[52] **U.S. Cl.** **623/49**; 623/50; 623/53; 623/55

[58] **Field of Search** 623/48-49, 623/53-56, 47, 50-52

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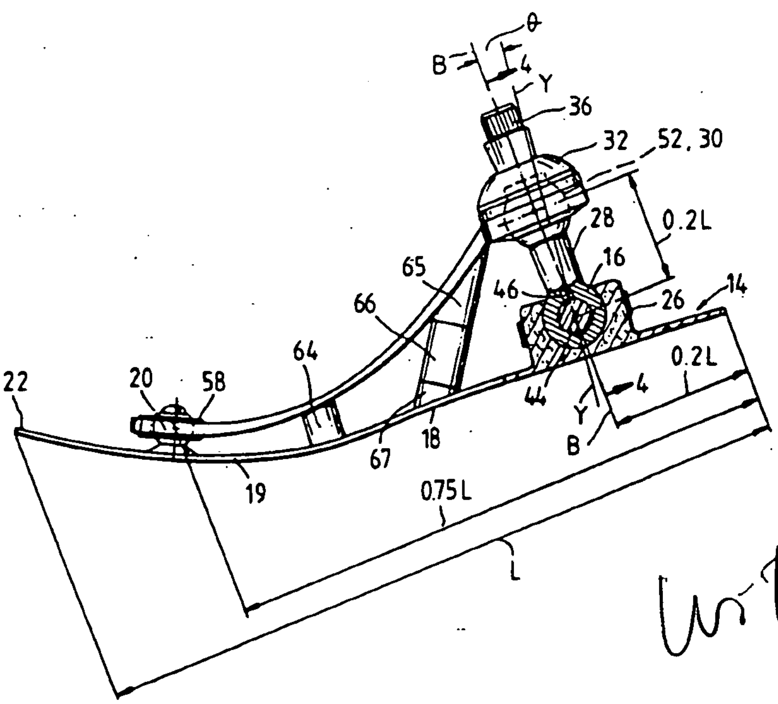
[57] **ABSTRACT**

A prosthetic foot comprises a flexible planter member, a flexible dorsal member, and a posterior pylon member connected by ball and socket joints. Elastic snubbers and torsion resistors aid in controlling the movement of the three structural members relative to each other. During ambulation, the foot deforms elastically to generate approximately the same forces and feel to the user as would be generated by the skeleton, muscles, tendons, and ligaments of a natural foot.

20 Claims, 3 Drawing Sheets



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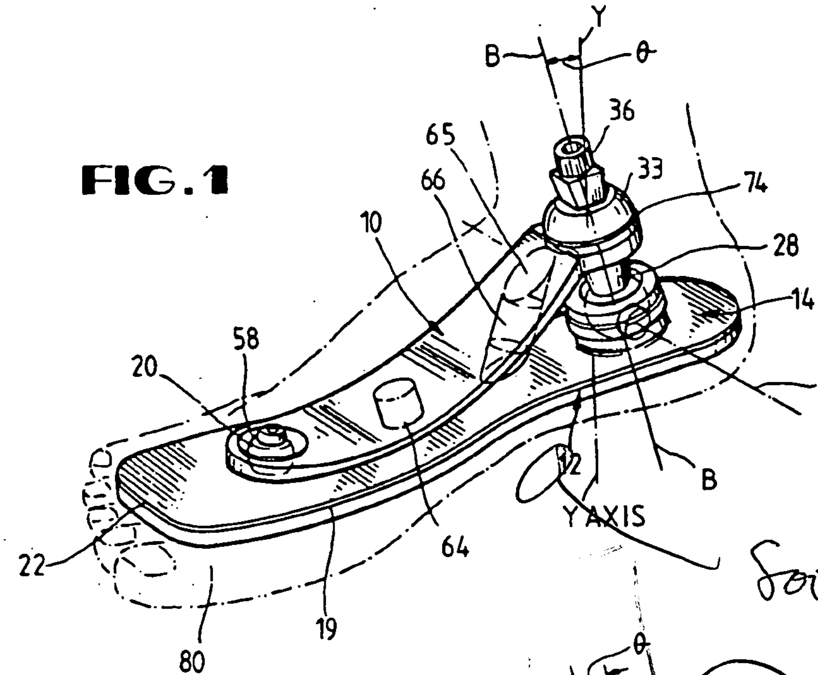
"L-shaped"

09/05/2001, EAST Version: 1.02.0008

FIG. 1



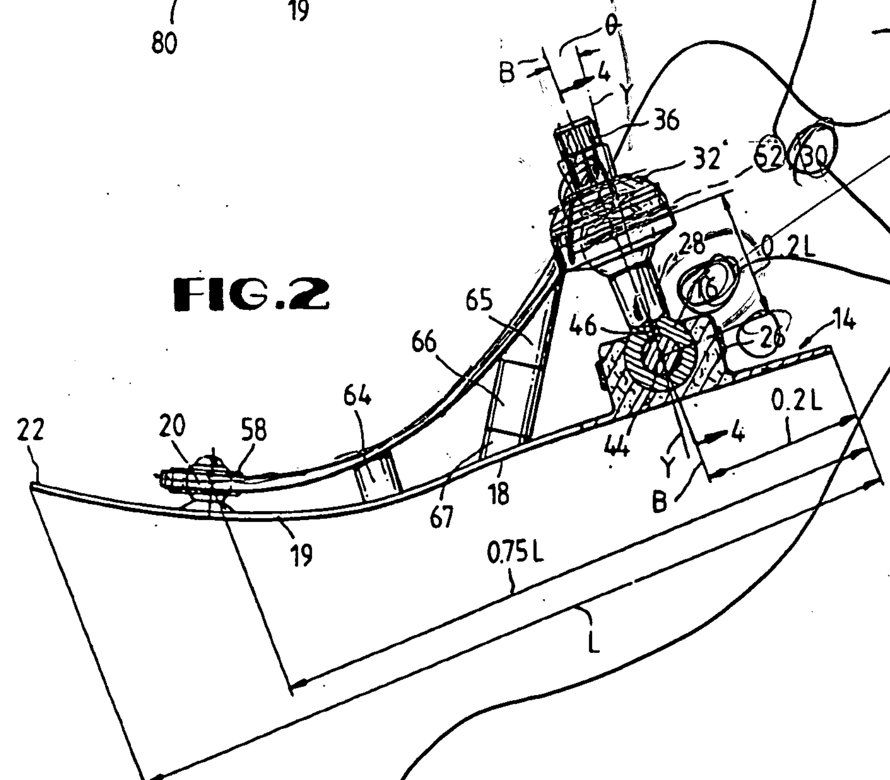
Socket

Foot plate (plantar)

Frame

Connection

FIG. 2



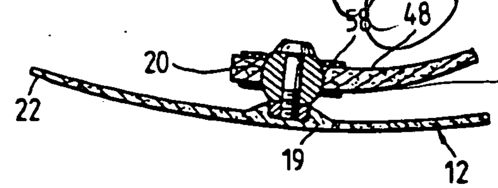
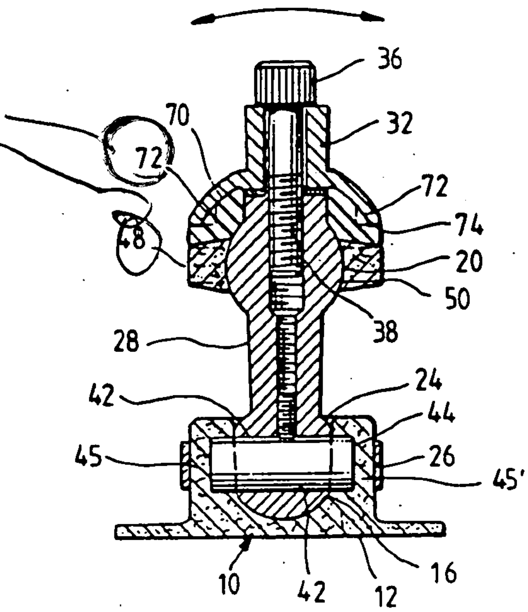


FIG. 3

FIG.4



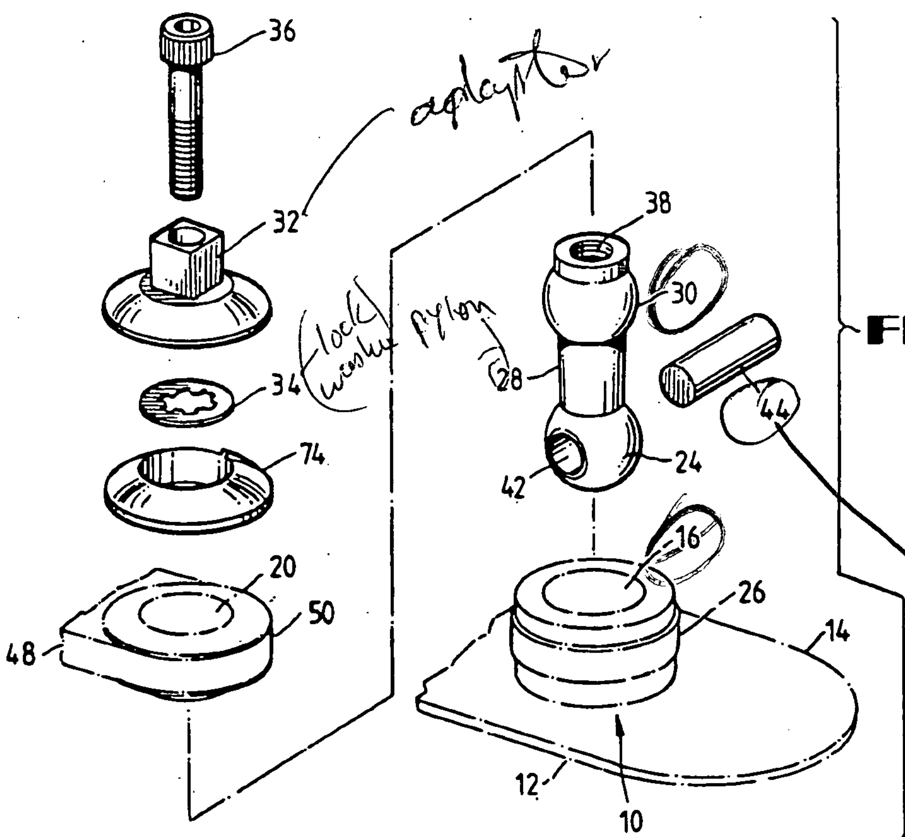


FIG.5

Anti rotational dampener

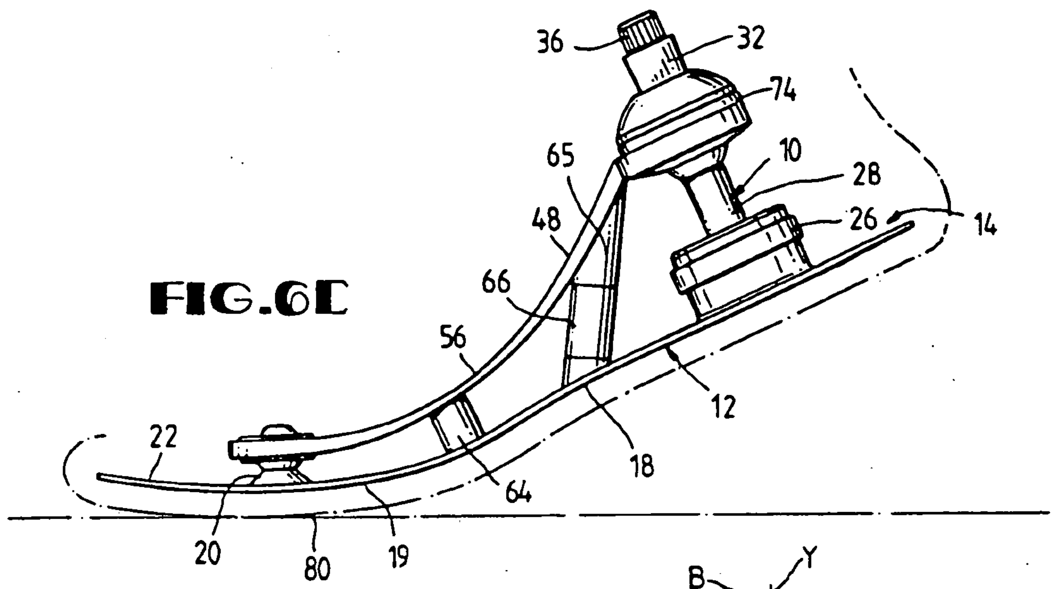


FIG.6C

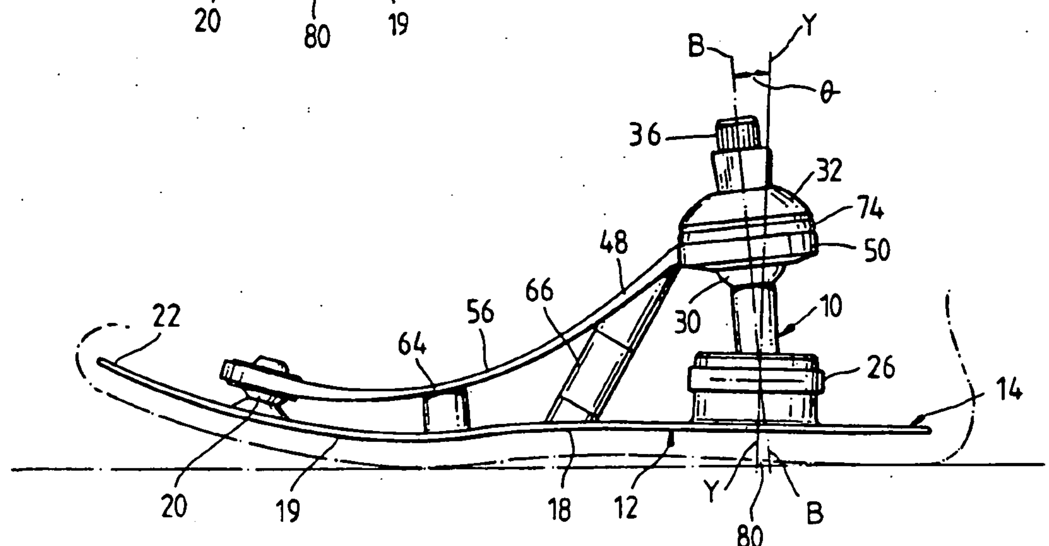


FIG.6B

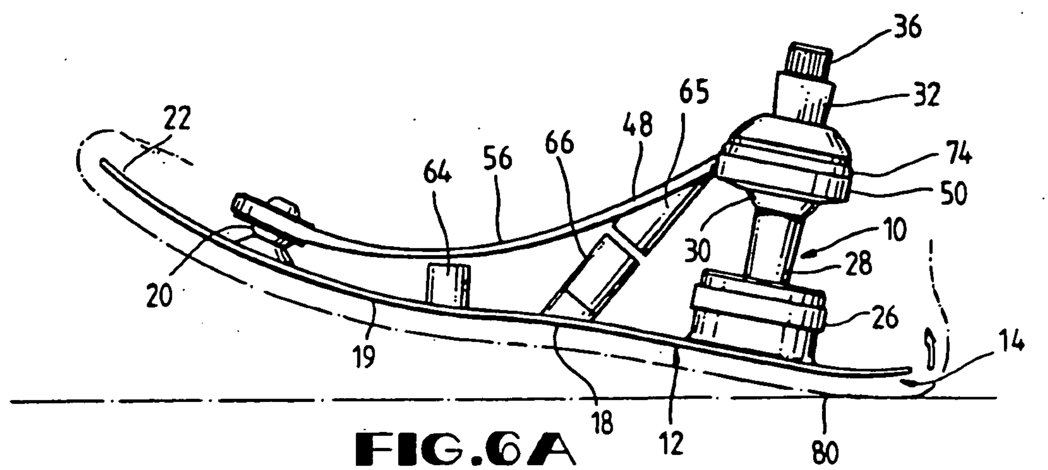


FIG.6A

PROSTHETIC FOOT

BACKGROUND OF THE INVENTION

A. Field of the Invention

The present invention is for a prosthetic foot having a flexible plantar member, a flexible dorsal member, and a posterior pylon member connected by ball and socket joints. Elastic snubbers and torsion resistors are positioned in between the plantar member and the dorsal member to aid in controlling the movement of the three structural members relative to each other. During ambulation, the design of the foot including the various ball and socket joints combined with the various elastic members function to allow the foot to deform elastically to generate approximately the same forces and feel to the user as would be generated by the skeleton, muscles, tendons, and ligaments of a natural foot.

B. Description of the Related Art

Artificial limbs and particularly prosthetic feet and legs have been known for centuries. The earliest were probably similar to the crude wooden "peg legs." These early devices enabled the user to stand and to walk awkwardly, usually with the additional aid of a crutch or cane.

In the early 20th century designers of artificial or prosthetic feet first attempted to duplicate the appearance and function of a natural foot. During the ensuing 70 or 80 years, the designs for prosthetic feet have remained relatively unchanged. What changes did occur seemed to come mainly from improvements in available materials. Classic prosthetic feet used spring principles to cushion shocks due to walking and running and allow some degree of movement of the foot. U.S. Pat. No. 1,294,632 to Dickson discloses such an artificial foot. More versions of the spring foot also known as an energy storing foot, are disclosed in U.S. Pat. No. 4,547,913, 4,645,509, and 4,822,363.

These devices have come to be known as energy storing feet because as the springs are deflected they store energy which is largely returned to the user as the foot elastically returns to its undeformed shape. The obvious disadvantages to such prosthetic devices are that springs alone poorly duplicate the deflections, forces, and feel to the user of a natural foot.

Designers have attempted to more closely approximate the action of a natural foot by adding ball and socket ankle joints geometrically similar to a natural anatomical ankle. Feet incorporating simulated ankle joints do theoretically allow for more natural movement, but copying the anatomical joint itself is not enough. Without all of the muscles, tendons, and cooperating bone structure of an anatomical foot, the anatomical type ankle joint is too unstable to be practical. Attempts to stabilize prosthetic ball and socket ankle joints are shown in U.S. Pat. Nos. 4,461,045 and 4,463,459, both issued to Shorter et al.

SUMMARY OF THE PRESENT INVENTION

The present invention radically departs from the known prior art by placing the prosthetic ankle joint at the bottom of the prosthetic foot rather than trying to simulate the natural anatomical ankle joint geometry. The prosthetic ankle joint shown herein is a ball and socket or more correctly a modified ball and socket joint. It is understood that other universal couplings can be used to simulate ankle movement and this invention is not limited to having ball and socket joints. Lowering the ankle joint to the bottom of the foot provides a tremendous increase in stability. In anatomical ankle joints, there is a tendency of the ankle joint to buckle, but this tendency is resisted by powerful leg muscles and tendons. Prosthetic feet which simulate the anatomical joint do not benefit from the stability provided by muscles, tendons and ligaments and, therefore, present an awkward buckling problem for the user. Lowering the prosthetic ankle joint to the base of the prosthetic foot reduces the moment around the joint and the resulting tendency to buckle to virtually zero.

In order to allow movement of the prosthetic foot that will approximate the movement of a natural foot, the invention includes secondary and tertiary ball joints. These bal joints assist in allowing inversion and eversion of the foot, but, because of the overall foot design, do not allow ankle buckling. The foot further comprises flexible plantar and dorsal members which combine the anatomical functions of natural foot muscles and skeleton. These members are connected by the socket joints and their relative motion can be controlled by elastic dampers, all of which will be described in more detail in the detailed description of the preferred embodiment.

In a natural foot, rigidity and flexibility are provided by the skeleton, which acts as a frame, and the surrounding muscles, tendons and ligaments which control movement. The individual bones of the skeleton are relatively rigid and inflexible so movement is provided for by interconnection of multiple bones joined together. The natural foot is held in shape yet allowed to flex and move for walking, running, and other human activity by muscles, tendons, and ligaments. In a natural foot, the muscles have a certain amount of inherent flexibility, but operate mainly by being contracted and relaxed by the brain. The instant invention simulates the combination of muscles and skeleton by use of a roughly triangular shaped skeleton whose members have designed-in flexibility and damping to simulate muscle action. The geometry of the structural members does not attempt to reproduce the geometry of a natural foot, as has been done by prior art, because lack of muscle control in a prosthetic foot requires entirely different structural considerations.

The combination of ball joints, rigid anterior pylon, flexible plantar and dorsal members, and interconnecting motion resisting dampers closely simulates the action and feel to the user of a natural foot. The combination provides a tremendous improvement over the prior art which used various configurations of leaf springs to allow movement.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective side view showing the invention with the cosmesis which surrounds it shown by phantom lines.

FIG. 2 is a side view of the invention shown without the cosmesis and with the bottom rear quarter cut away to show the primary ball and socket joint.

FIG. 3 is a partial side view of the toe area cut away to show the tertiary ball and socket joint.

FIG. 4 is a section of the invention shown in FIG. 2 as viewed from the rear.

FIG. 5 is an exploded view of the posterior portion of the invention showing the relationship of the heel, the pylon, the primary and secondary ball joints, and the adaptor.

FIG. 6A is a side view of the invention shown as the heel contacts the ground during a step.

FIG. 6B is a side view of the invention shown during the middle of a step as weight is transferred from the heel to the ball area.

FIG. 6C is a side view of the invention shown near the end of a step just as all the weight is transferred to the toe area.

DETAILED DESCRIPTION OF A PREFERRED EMBODIMENT

Refer first to FIGS. 1 and 2. The prosthetic foot 10 is built on a flexible plantar member 12 with a heel portion 14, a primary socket 16, an arch portion 18, a ball portion 19, including a tertiary ball 20, and a toe portion 22. The size of the plantar member 12 varies according to individual user needs. In order to describe geometric relationships of various members of the foot 10, the plantar member will be referred to as having a length "L". Other dimensions will then be referred to as being some percentage of the length L.

Material

In experimental models, plantar members have been constructed of fiberglass and carbon fibers embedded in epoxy resins. The plantar member 12 serves the same function as the keel of a ship and the remaining components are built using it as the base. A particularly successful prosthetic foot 10 employed a plantar member 12 made of unidirectional glass fibers running along the length of the foot 10 and embedded in Hexcel 2316 semirigid epoxy. Fiberglass material weighing 13.8 ounces per square yard was laminated nine layers thick at the arch portion 18 and tapered to four layers thick at the heel portion 14 and toe portion 22. Models have been made using plantar members approximately 1½ to 2½ inches wide at the heel and toe portions with an hourglass-shaped taper into the arch portion of about 1 to 1½ inches in width as shown in FIG. 1. The actual physical dimensions of the foot depend on the size of the patient to be fitted, but the hourglass configuration has been shown to help approximate the correct flexural feel during use.

Between the heel portion 14 and the arch portion 18 is located a primary socket 16 which is molded in place around a primary ball 24. The primary socket 16 is located approximately 20% of the length (L) of the plantar member 12 from its rearmost edge. The primary socket 16 is located as near the bottom of the plantar member 12 as is structurally feasible to increase stability and reduce buckling of the related joint. For added strength and rigidity, the primary socket 16 is surrounded by a cylindrical steel band 26.

Still referring to FIGS. 1 and 2, a rigid posterior pylon 28 which terminates on its lower end in the previously mentioned primary ball 24 may be seen. The pylon 28 extends upward and inclines toward the toe portion 22 of the foot 10 at an angle Θ of approximately 15 degrees from a vertical y-axis extending from the foot to the user's anatomical knee joint (not shown). The angle Θ may be varied to accommodate the physical characteristics of individual users. The pylon 28 includes a secondary ball 30. The center of the secondary ball 30 is located above the center of primary ball 24 a distance of approximately 20% of the total length (L) of the plantar member 12. The pylon 28 terminates above the secondary ball 30 in a configuration adapted to receive a commercially available adaptor 32 that enables the prosthetic foot 10 to be connected to a prosthetic leg member (not shown). The pylon 28 and balls 24, 30 are subject to extreme loads during use and experimental models have been machined from solid billets of high strength aluminum alloy. Commercial models may use cast or forged titanium alloy pylons and balls to keep weight and cost as low as possible while achieving the necessary strength.

For a complete understanding of the relationship of the pylon 28, the primary and secondary joints, and the adaptor 32 refer also to details shown by FIGS. 4 and 5. The particular adaptor 32 shown and found to be most satisfactory in use is an Endoskeletal Foot Adaptor manufactured by Otto Bock in West Germany. The adaptor 32 fits over the pylon 28 and is held in place by a lock washer 34 and a bolt 36 threaded into the pylon 28.

Below the bolt 36, the pylon 28 is hollow and a threaded hole 38 extends down through the pylon 28 along its longitudinal axis B—B. A second cylindrical hole 42 extends transversely through the primary ball 24. A cylindrical primary antirotational damper 44 extends through the hole 42 and into recesses 45, 45' in each side of the primary socket 16. The primary antirotational damper 44 is made of rubber, neoprene, or high density urethane. It operates to pin the ball 24 in socket 16 and allow rotation only about the horizontal z axis which is transverse to the longitudinal y axis of the foot 10. Because the damper 44 is not rigid but made of resilient material, a very limited rotation of the ball 24 about the x and y axes is also allowed. The damper 44 elastically resists rotation about the x and y axes and tends to return the ball 24 to its initial position with respect to these axes whenever it is moved by external forces. A threaded screw 46 can be screwed into the threaded hole 38 to compress the damper 44 and alter its elastic characteristics. As screw 46 is tightened, it extends into the damper 44 compressing it into the confined space of hole 42 and causing it to become more rigid and resistant to motion. Screw 46 is preadjusted to the required characteristics of a particular individual before bolt 36 is inserted to clamp the adaptor 32 in place.

Referring now back to FIGS. 1 and 2, extending from the secondary ball 30 of the pylon 28 to the toe portion 22 of plantar member 12 is a curved flexible dorsal member 48. The dorsal member 48 includes a rigid anterior portion 50 with a socket 52 to receive ball 30 and form a secondary ball and socket joint (30, 52). The dorsal member 48 extends forward in a flexible anterior portion 56 (see FIG. 6A) to a tertiary socket 58 which receives tertiary ball 20 rigidly attached to the plantar member 12 between the toe portion 22 and the arch portion 18. The center of tertiary ball and socket joint (20, 58) is located approximately 0.75L (75% of the total length L of the plantar member 12) from the rear edge of the plantar member 12. Refer to FIG. 3 for a cross-sectional detail of the tertiary ball and socket joint.

Experimental modes of the foot 10 have used dorsal members 48 made of the same basic materials and construction as the corresponding plantar members 12. One successful model uses a dorsal member with six layers of unidirectional glass fiber cloth. The fibers extend from the front of the member 48 to the rear and are bonded in a base material of Hexcel 2316 semirigid epoxy.

In addition to the ball and socket joints, plantar member 12 is connected to dorsal member 48 by an elastic snubber 64 and an elastic shear reducer 66. The snubber 64 is made of rubber, high density urethane, or other elastic material and is bonded to the plantar member 12

between the arch 18 and the ball and socket joint (20. 58). It extends upward to contact the dorsal member 48. The purpose of the snubber 64 is to act as a compression member so that a downward deflection of dorsal member 48 will transmit force via the snubber 64 into the plantar member 12, thereby increasing the overall stiffness of the foot 10. A downward deflection of plantar member 12 does not transmit force into the dorsal member 48 because in the preferred embodiment the snubber 64 is not bonded to dorsal member 48 and cannot be placed in tension. This causes a unique asymmetric resistance to bending of the foot. The foot is stiffer in resistance to forces and moments which tend to deflect dorsal member 48 downward with respect to plantar member 12 than in resistance to forces and moments which tend to deflect dorsal member 48 upward with respect to plantar member 12. The amount of asymmetry can be varied by changing the size, shape, and elastic modulus and location of snubber 64.

Experimental model which have exhibited particularly good characteristics of feel, locate a cylindrical snubber 64 having a Shore hardness of about 140 approximately 3½ inches behind the tertiary ball and socket joint (58. 20). Sniffness has been varied by changing the snubber diameter from ½ inch to 9/16 inch to ⅝ inch.

The shear reducer 66 is an elongated member also made of rubber, high density urethane, or other similarly stiff elastic material which extends from the rigid anterior portion 50 of dorsal member 48 down and forward to the arch portion 18 of plantar member 12. More rigid members of the shear reducer may be made of materials identical to those of the rigid anterior portion 50 of dorsal member 48 and of the rigid arch portion 18 of plantar member 12. As such, these two additional members (as shown in FIG. 2 as supports 65 and 67, respectively) provide contact structures for the elongated elastic member 66. The purpose of shear reducer 66 is to absorb impact forces generated at secondary ball and socket joint (30. 52) which tend to push dorsal member 48 forward and shear the tertiary ball and socket joint (20, 58). Models with and without shear reducer 66 have been tested and the life of ball and socket joint (20. 58) is significantly improved by the presence of the shear reducer 66.

Finally, referring to FIG. 4, the endoskeletal foot adaptor 32 includes a recess 70 and an internal web 72. The recess is filled with a molded elastic material such as rubber or high density urethane. The elastic material extends slightly below the recess and forms an elastic cushion 74 between the adaptor 32 and the dorsal member 48. The cushion 74 is bonded to the rigid portion 50 of member 48. By means of the bonding and the web 72, rotation of the adaptor 32 with respect to dorsal member 48 is elastically resisted. This allows for the slight rotation of the foot 10 relative to the leg (not shown) of the user which is necessary for simulation of natural walking. In its final form, the entire skeletal framework is preferably covered by a cosmesis 80 made of expanded PVC or polyethylene so that the prosthetic foot has the cosmetic appearance of a natural foot.

OPERATION OF THE PROSTHETIC FOOT INVENTION

The operation of the prosthetic foot 10 will be detailed through one step of the user starting with heel strike. Refer now to FIG. 6A. At heel strike the cosmesis 80 contacts the ground and transmits force to heel 14 of the plantar member 12. The heel portion 14 flexes upward absorbing the impact of the heel strike and storing energy to return the foot 10 to its relaxed position. As the heel portion 14 deflects the resultant forces produce a moment about the primary ball and socket joint and the plantar member 12 tends to rotate around the z axis with respect to the pylon 28. Slight rotation occurs but is resisted by tension in dorsal member 48. The floor reaction at the heel 14 also creates a downward distortion of the plantar member 12 between the primary ball and socket joint (24. 16) and the tertiary ball and socket joint (20. 58). The snubber 64 and the shear reducer 66 tend to separate slightly from their respective supports. Downward distortion of the plantar member 12, tension in dorsal member 48, and related slight rotation of the three ball and socket joints simulates natural plantar flexion.

Refer now to FIG. 6B. As the user approaches mid-stance, the heel portion returns to normal relaxed shape and the user's weight is gradually transmitted to the area under the primary ball 24 and socket 16 and the ball portion 19. Also at approximately mid-stance, the moment between the pylon 28 and the plantar member 12 decreases to zero and the tension on the dorsal member 48 is eliminated. The foot 10 returns to essentially its relaxed position and snubber 64 and shear reducer 66 again contact their supports.

As the step continues, load is transferred to the ball portion 19 of the foot 10 and the pylon 28 tends to rotate counterclockwise around the z axis with respect to the plantar member 12. This reverses the earlier moment and dorsal member 48 is placed in compression and tends to flex downward with respect to plantar member 12. This combination of forces and moments places shear reducer 66 in compression reducing the load in the x direction that would otherwise be transmitted to the tertiary ball and socket joint (20. 58).

As the dorsal member 48 tends to deflect downward with respect to the plantar member, it compresses snubber 64 and transfers load into the plantar member 12, thereby increasing the overall stiffness and energy absorbing ability of the foot 10. Simultaneously, normal rotation of the hips of the user during a step rotates the user's leg slightly around the y-axis. This rotation is allowed but resisted elastically by the elastic cushion 74 and the primary antirotational damper 44 allowing the foot to remain stationary relative to the y axis. Without the ability to compensate for this slight rotation of the hips, the foot 10 would also rotate at this crucial point in the step transmitting an unnatural feeling torque from the floor to the user's leg. Also, because the axis B—B of the pylon 28 is angled relative to the vertical y-axis, the rotation about the pylon also causes an inversion moment of the foot around the x axis. This moment is also elastically resisted by the antirotational damper but movement is allowed to a slight extent by the primary and secondary ball and socket joints. This further enhances the natural feel and movement of the foot 10 during the step.

Now refer to FIG. 6C. As the step progresses, all of the weight is transmitted to the toe portion 22 of the plantar member 12 causing the toe to bend upward and further increasing the stresses on the dorsal member 48, the shear reducer 66, and the snubber 64.

Finally at toe off, the elastic stresses stored in the foot 10 cause it to again return to its undeformed shape and in doing so release the stored energy to push the user through the step.

Throughout the entire step cycle from heel contact to toe off, the plantar member 12 and dorsal member 48 act simultaneously and instantaneously, providing a smooth transition of torque through the primary and secondary ball and socket joints.

The present invention has been described in terms of particular embodiments found or proposed to comprise preferred modes for the practice of the invention. It will be appreciated by those of skill in the art that, in light of the present disclosure, numerous modifications and changes can be made in the particular embodiments exemplified without departing from the intended scope of the invention. For example, while a preferred embodiment of the invention utilizes ball and socket joints at several positions in the prosthetic device, the joints could equally as well be designed using any of a number of such universal joints known to those of skill in the art. All such modifications are intended to be included within the scope of the appended claims.

What is claimed is:

1. A prosthetic foot, comprising:

a plantar member having first and second end portions, a primary socket connected to said plantar member adjacent said first end portion with said primary socket further positioned closely to a bottom horizontal surface of said plantar member, and a tertiary ball connected to said plantar member adjacent said second end portion;

a pylon having a first and second end, a primary ball attached to said first end of said pylon, a secondary ball attached to said pylon spaced from said primary ball, and an adaptor assembly attached to said second end of said pylon, said pylon being connected to said plantar member by said primary socket engaging said primary ball; and,

a dorsal member having first and second end portions, a secondary socket connected to said dorsal member adjacent said first end portion of said dorsal member and a tertiary socket connected to said dorsal member adjacent said second end portion of said dorsal member, said dorsal member being connected to said pylon by said secondary ball engaging said secondary socket, and said dorsal member being connected to said plantar member by said tertiary socket engaging said tertiary ball.

2. A prosthetic foot as in claim 1, wherein said dorsal and plantar members are flexible and said pylon is rigid.

3. A prosthetic foot as in claim 1, further comprising at least one snubber member adhesively attached to said plantar member at points spaced from said balls and sockets, which snubber member, upon downward deflection of said dorsal member transmits force via said snubber member into the plantar member, thereby increasing overall stiffness of said prosthetic foot.

4. A prosthetic foot as in claim 1, further comprising a shear reducer member connected to said dorsal member adjacent said secondary socket and connected to said plantar member at a point approximately midway between said primary socket and said tertiary ball.

5. A prosthetic foot as in claim 3, wherein said snubber member is at least partially made of an elastic material having a Shore hardness between 120 and 160.

6. A prosthetic foot as in claim 3, wherein the position of said snubber along said plantar member is approximately 3½ inches from said tertiary ball toward a heel of said foot.

7. A prosthetic foot as in claim 3, wherein the stiffness of said snubber is varied by altering the diameter of said snubber.

8. A prosthetic foot as in claim 1, wherein said primary ball has an aperture through its center capable of receiving an antirotational member, said primary socket has mating recesses on either side of the primary ball, and said antirotational member extends through said aperture of said primary ball into each of said recesses in said primary socket to pin said primary ball and said primary socket together and inhibit rotation of said primary ball with respect to said primary socket around all but one axis.

9. A prosthetic foot as in claim 8, wherein said antirotational member may be variably compressed by a threaded screw which is screwed into a threaded aperture cut longitudinally through said pylon above said primary ball containing said antirotational member in order to cause said antirotational member of become more rigid and resistant to motion.

10. A prosthetic foot as in claim 6, wherein said primary socket containing said primary ball is made more rigid by the addition of a cylindrical metal band surrounding said primary socket.

11. A prosthetic foot as in claim 2, wherein said plantar member and said dorsal member are constructed with a variable number of layers of unidirectional glass fiber cloth, the fibers of which said cloth running parallel to the length of said prosthetic foot and said cloth being embedded in a semirigid epoxy.

12. A prosthetic foot as in claim 1 wherein said adaptor assembly comprises an endoskeletal foot adaptor which fits over said pylon and is held in place on said pylon by a bolt and lock washer, said bolt being threaded into the pylon, said endoskeletal foot adaptor including a recess and an internal web.

13. A prosthetic foot as in claim 12, wherein said recess in said endoskeletal foot adaptor is filled with a molded elastic material extending slightly below the recess and forming an elastic cushion between said adaptor and said dorsal member to which said elastic material is bonded in a manner to cause elastic resistance to rotation of said adaptor with respect to said dorsal member and allows slight rotation of said prosthetic foot relative to a user's leg as necessary for simulation of natural walking.

14. A prosthetic foot as in claim 1, wherein said plantar member has wider heel and toe portions in respect to a narrower arch portion.

15. A prosthetic foot as in claim 1, wherein the center of said secondary ball is located above the center of said primary ball at a distance of approximately 20% of the length of the plantar member.

16. A prosthetic foot as in claim 1, wherein said plantar member is affixed to a cushioning layer along its entire bottom surface.

17. A prosthetic foot as in claim 1, wherein a cosmesis covers said foot.

18. A prosthetic foot as in claim 1, wherein said pylon is constructed from solid billets of high strength aluminum or titanium alloys.

19. A prosthetic foot as in claim 4, wherein said shear reducer member is at least partially made of an elastic material having a Shore hardness between 120 and 160.

20. A prosthetic foot, comprising:

a flexible plantar member having first and second end portions wider in respect to a narrower central portion, said plantar member being constructed

with a variable number of layers of unidirectional glass fiber cloth. the fibers of which said cloth run parallel to the length of said prosthetic foot. which said cloth is embedded in a semirigid epoxy. a primary socket connected to said plantar member adjacent said first end portion, said primary socket further positioned closely to a bottom horizontal surface of said plantar member. said primary socket having mating recesses on either of two opposite sides. at least one snubber member at least partially made of an elastic material having a Shore hardness between 120 and 160 adhesively attached to said plantar member at least one point between said first and second end portions of said plantar member, a shear reducer member at least partially made of an elastic material having a Shore hardness between 120 and 160 capable of reversibly contacting said dorsal member adjacent a secondary socket. said dorsal member connected to said plantar member at a point approximately midway between said primary socket and a tertiary ball connected to said plantar member adjacent said second end portion:

a rigid pylon having a first and second end. a primary ball attached to said first end of said pylon, said primary ball having an aperture through its center capable of receiving an antirotational member which extends through said aperture of said primary ball into each of said recesses in said primary socket to pin said primary ball and said primary socket together and inhibit rotation of said primary ball with respect to said primary socket around all but one axis, which antirotational member may be variably compressed by a threaded screw which is screwed into a threaded aperture cut longitudinally through said pylon above said primary ball containing said antirotational member in order to cause said antirotational member to become more rigid and resistant to motion. which said primary socket containing said primary ball is made more rigid by the addition of a cylindrical metal band surrounding said primary socket. a secondary ball attached to said pylon spaced from said primary ball at a distance of approximately 20% of the length of said plantar member. and an adaptor assembly attached to said second end of said pylon comprising an endoskeletal foot adaptor which fits over said pylon and is held in place on said pylon by a bolt and lock washer. said bolt being threaded into the pylon where said endoskeletal foot adaptor includes a recess and an internal web and where said recess in said endoskeletal foot adaptor is filled with a molded elastic material. said molded elastic material extending slightly below the recess and forming an elastic cushion between said adaptor and said dorsal member to which said elastic material is bonded, said elastic material being bonded in a manner to cause elastic resistance to rotation of said adaptor with respect to said dorsal member and to allow slight rotation of said prosthetic foot relative to a user's leg as necessary for simulation of natural walking. said pylon being connected to said plantar member by said primary socket engaging said primary ball;

said dorsal member having first and second end portions and being constructed with a variable number of layers of unidirectional glass fiber cloth. the fibers of which said cloth run parallel to the length of said prosthetic foot, said cloth being embedded in a semirigid epoxy, a secondary socket connected to said dorsal member adjacent said first end of said dorsal member, and a tertiary socket connected to said dorsal member adjacent said second end of said dorsal member, said dorsal member being connected to said pylon by said secondary ball engaging said secondary socket. and said dorsal member being connected to said plantar member by said tertiary socket engaging said tertiary ball; and.

a cosmesis covering said foot.

* * * * *

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ANKLE JOINT

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Fig.4.

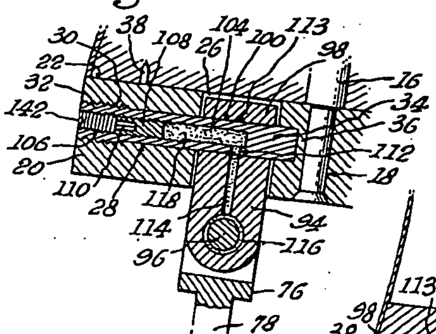
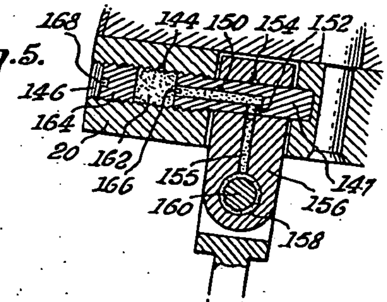


Fig.5.



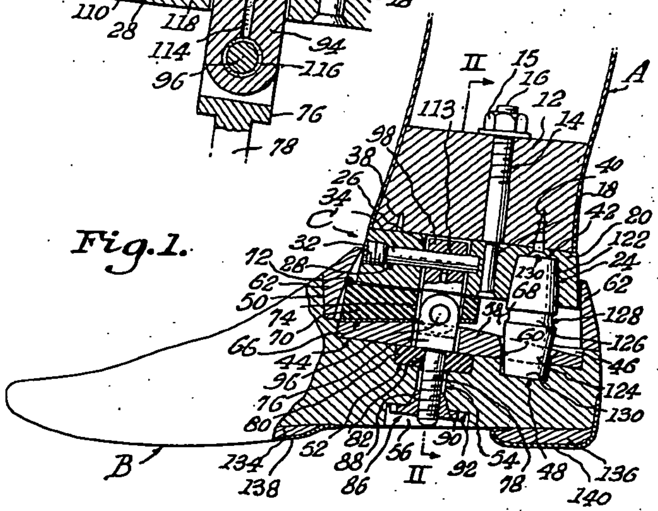


Fig.1.

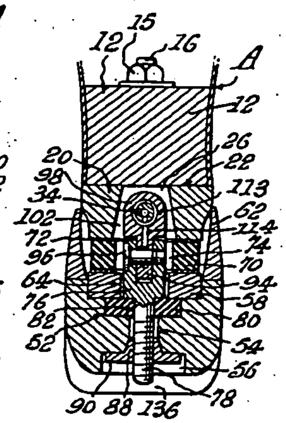


Fig.2.

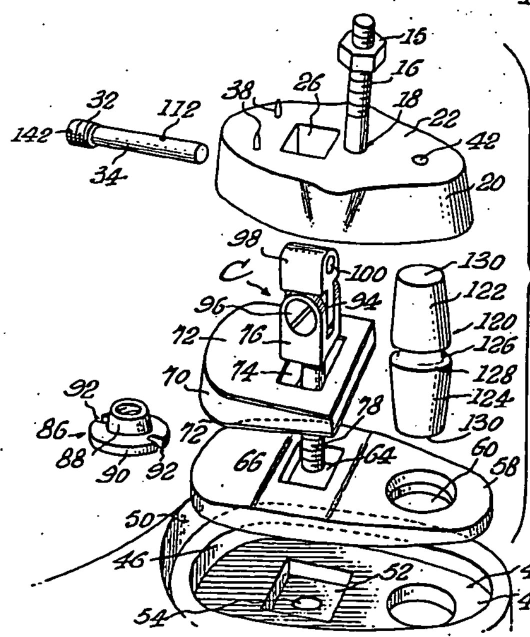


Fig.3.

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Fig. 9.

Fig. 6.

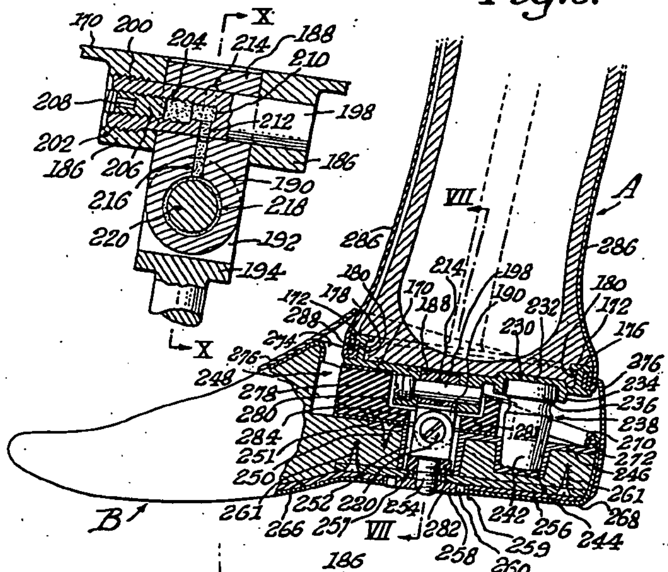


Fig. 7.

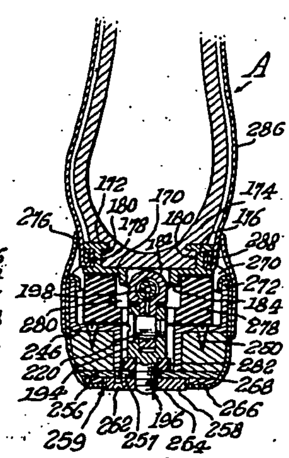
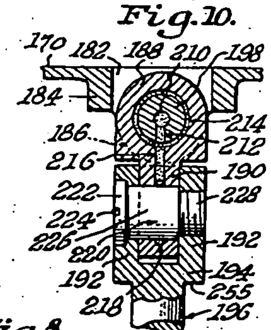


Fig. 10.



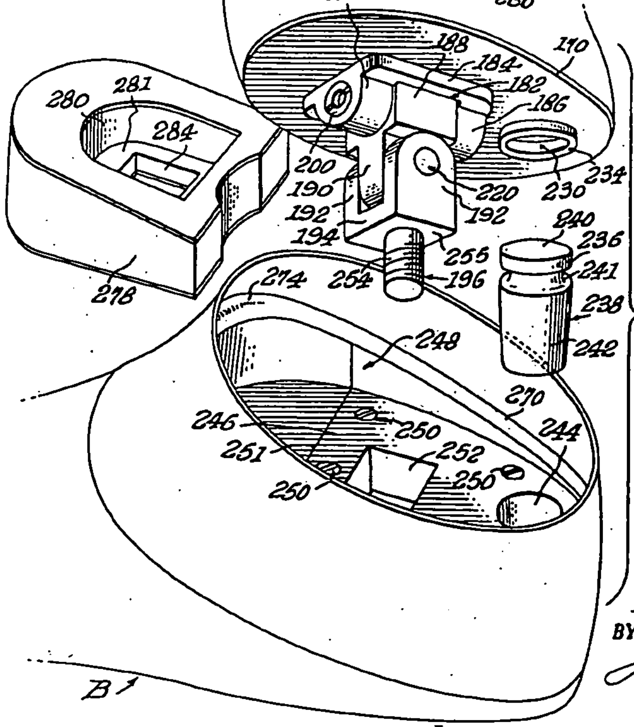


Fig. 8.

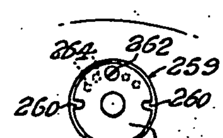


Fig. 11.

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ANKLE JOINT

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Application September 29, 1953, Serial No. 383,151

5 Claims. (Cl. 3—32)

(Granted under Title 35, U. S. Code (1952), sec. 266)

The invention described herein may be manufactured and used by or for the Government for governmental purposes, without payment to me of any royalty thereon.

The present invention relates to an improved prosthetic foot and leg assembly and an improved interconnecting ankle joint construction providing naturally simulated movements between such foot and leg, and which may be worn by an amputee having had an amputation of either or both of his natural legs either above or below the knee, or an amputation at one or both ankles.

The improvements of the present construction are related principally to the construction of an improved ankle joint which is adapted to fit interchangeably either a right or left leg or foot prosthesis without inconvenience to the amputee, and which eliminates the need for a selection of a particular joint construction to fit a particular prosthesis. Also, the improved ankle joint construction of the present invention enables a substantially universal articulation of the foot member relative to the ankle joint, thereby providing an amputee with free motion of the foot which can be controlled by a simple adjustment. Additionally, the present improvements comprise means for providing continuous pressure lubrication for all moving parts of the ankle joint for assuring smooth and noiseless operation of such parts at all times.

The foregoing is indicative of the principal objects of the present invention, although further objects and advantages of the present construction will become apparent as the description proceeds, and the features of novelty will be pointed out in particularity in the appended claims.

The invention will be understood more readily by reference to the accompanying drawings, in which

Fig. 1 is a sectional side elevation of one embodiment of an improved ankle joint including the features of the present invention;

Fig. 2 is a sectional elevation taken on the line II—II of Fig. 1, looking in the direction of the arrows;

Fig. 3 is a disassembled perspective view of the construction of Figs. 1 and 2;

Fig. 4 is a fragmentary sectional elevation on an enlarged scale showing one form of longitudinal and lateral pivot means, together with lubricating means therefor;

Fig. 5 is a view similar to Fig. 4 but showing a somewhat modified embodiment of the parts shown in Fig. 4;

Fig. 6 is a sectional elevation of a still further modified embodiment of the construction;

Fig. 7 is a detailed sectional elevation taken on the line VII—VII of Fig. 6, looking in the direction of the arrows;

Fig. 8 is a disassembled perspective view of the embodiment shown in Fig. 6;

Fig. 9 is a fragmentary sectional elevation of longitudinal and lateral pivot means employed in the embodiment of Fig. 6, with lubricating means therefor, the parts being shown on an enlarged scale;

Fig. 10 is an enlarged sectional elevation taken on the line X—X of Fig. 9, looking in the direction of the arrows; and

Fig. 11 is a fragmentary bottom view of the foot element for either of the embodiments of the improved ankle joint of the present invention, the view indicating means enabling adjustment of the said joint for assembly thereof.

Referred to in general terms, it will be seen that

the present construction comprises improvements in prosthetic ankle joint constructions interconnecting a prosthetic leg and foot, the latter being adapted for both longitudinal and transverse pivotal movements relative to the leg, and also for a combination of such movements, so that the foot is adapted for substantially universal movements relative to the leg. Such movements are effected by a pair of pivot assemblies disposed at right angles to each other, which enable a longitudinal pivotal fore and aft movement of the foot relative to the leg, a lateral rocking movement of the foot to either side of the leg, or a combination longitudinal and lateral rotary movement which is a resultant of the fore and aft and lateral rocking movements, thereby providing for substantially universal movement between the foot and leg. Also, cooperating with the right-angularly disposed pivots, are resilient means in both the posterior (heel) and anterior (metatarsal) portions of the foot for returning and retaining the foot in normal position relative to the leg following displacements of the foot in any direction.

Referring more particularly to the drawings, it may be pointed out that the improved construction of the present invention provides a universal ankle joint which is adapted to either type of prosthetic appliance that is provided customarily for a leg amputation that has been performed either above the knee or below the knee, or where there has been an amputation of the foot at the ankle, such appliances being referred to customarily as AK, BK, and Symes, respectively. In the drawings, the improved ankle joint construction is employed in connection with either an AK or BK prosthetic leg illustrated in the embodiment illustrated in Figs. 1 through 5 of the drawings, and in Figs. 6 through 10 there is illustrated a construction of the improved joint embodied in a Symes-type of prosthesis.

Referring more particularly to Figs. 1 through 5, reference character A represents a fragment of a mechanical or prosthetic leg of either an AK or a BK type, having a foot element B connected thereto through the improved ankle joint construction designated generally at C. As has been indicated above, the improvements of the present invention are comprised in the ankle joint C to provide longitudinal and lateral tilting movements of the foot member B relative to the leg member A, and also a rotary movement of the foot member, all as selectively controlled by the wearer of the prosthesis. Additionally, the improved ankle joint construction is capable of ready disassembly as well as reassembly, and is suitable equally for right and left leg prostheses, thereby minimizing inconvenience to the wearer, particularly when the wearer is a bilateral amputee, as the present construction is applicable interchangeably to either a right- or left-sided amputation.

The leg member A of Figs. 1, 2, and 3 is shown as being hollow, with the lower end closed by a wooden plug 12 having a hole 14 extending therethrough for the reception of attaching bolt 16 for the improved ankle construction. The attaching bolt 16 also passes through a hole 18 in a top attaching head plate 20 of the improved ankle joint, which head plate, in practice, is a thick metallic casting composed of a light metal, for example, aluminum or magnesium or a light metal alloy. The top surface 22 of this head plate 20 is substantially planar and is in coextensive engagement with the bottom surface of the closure plug 12. A deep, inwardly tapering heel recess 24 is provided in the head plate 20, the longitudinal axis of which recess parallels the longitudinal axis of the attaching bolt 16 and is centrally located with respect to the sides of the head plate or section 20, this recess 24 being located symmetrically in the casting of the head plate or section 20 with respect to the attaching bolt 16 and the rear and lateral surfaces of the said casting. A square hole 26 extends vertically all the way through the head plate 20 in advance of the attaching bolt 16, and a horizontally-extending bore 28 is provided in the head plate 20, which bore passes from the front face of the head plate to the square hole 26 and extends beyond the latter, terminating just short of the attaching bolt 16. The bore 28 is threaded internally adjacent to its forward end, as is designated at 30, for receiving externally

threaded head 32 of a tubular pivot screw 34 which is mounted in the bore 28 and extends to rear closure 36 of this bore.

The head plate 20 is provided with spaced forward pins 38 which extend into the leg plug 12 and hold the head plate properly positioned relative to this leg plug or closure 12, the rear attachment of the head plate being effected by a screw 40 which is located in a screw hole 42 that communicates with the heel recess 24 in the head plate 20.

The foot element B is constructed of any suitable material, preferably willow wood, which is relatively tough and light in weight. In the top of the foot B is a cavity 44 providing an upwardly opening recess 46 which encloses completely the improved ankle joint and all associated parts. The cavity 44 extends from the forward or metatarsal arch portion of the foot B to the heel thereof and is deepened into a circular heel recess 48 which corresponds in size and shape with the heel recess 24 in the head plate 20, and, when the elements are assembled, becomes aligned therewith. The metatarsal arch portion of the foot B defines a forward abutment 50 for the cavity 44, such extending above the forward peripheral portions of the cavity, the bottom of this cavity being provided also with a square recess 52, a hole 54 extending from this recess 52 into an enlarged bottom recess 56 in the instep portion of the foot B.

The cavity 44 in the foot B is approximately oval in peripheral contour, with the wide area of the oval towards the toe of the foot. This cavity 44 receives and seats a base plate 58 of the ankle joint assembly provided by the present construction. This base plate 58 is received snugly in the cavity 44 and is provided with a round hole 60 in its heel or restricted end, which hole corresponds in size and shape to, and which registers with, the heel recess 48 in the bottom of cavity 44. The peripheral surface of the cavity 44 forms a seat for a flexible collar 62 that extends upwardly and encloses the lower portions of the head plate 20, the cavity 44 also housing the ankle joint and associated parts, the said abutment portion 50 acting as a retaining stop for the forward portions of the collar 62.

A square hole 64 in the base plate 58 registers with the square recess 52 in the bottom of cavity 44 when the base plate 58 is seated in the cavity, the top surface 66 of the base plate sloping downwardly both forwardly and rearwardly, a clearance 68 being provided between this top surface 66 and the planar bottom surface of the head plate 20. This clearance 68 is closed forwardly by a wedge-shaped resilient (rubber) cushion 70 which has a top and bottom wear-resisting leather covering 72, the covering 72 being in engagement with the bottom surface of the head plate 20 and the forward downwardly sloping top surface of the base plate 58. The resilient cushion 70 forms a forward cushion for longitudinal pivotal motion of the foot B, and the tightness with which this foot is drawn against the cushion 70 controls the said longitudinal pivotal motion of the foot B. This cushion 70 is provided with a square hole 74 extending therethrough, which is provided to register with the square hole 64 in the base plate 58.

The above-mentioned longitudinal pivotal movement of the foot B relative to the leg A is effected by providing a pivot bolt having an enlarged bifurcated upper or head end 76 from which depends a threaded shank 78, the bifurcated head end extending into the square hole 26 in the head plate 20, this hole 26 being sufficiently large to allow for a loose play between the outside of the said end 76 and the sides of the hole 26. The head 76 also is received in the square hole 74 in the forward cushion 70 and also in the square hole 64 of the base plate 58, the head 76 seating on a resilient collar 80 which is inserted in the square recess 52 in the foot B and which has a hole 82 that is aligned with the hole 54 that extends through the foot B, the threaded shank 78 extending through these holes 82 and 54 and through the bottom of the foot B. The latter hole opens into the enlarged recess 56 for reception of a control nut 86 received on shank 78, the nut having an internally threaded flange 88, the said internal threads of which are complemental to the threads on the shank 78. The control nut 86 acts to pull upon the shank 78, and the flange 90 of this nut 86 desirably is provided with diametrically opposite peripheral recesses 92 for receiving a spanner wrench, by means of which the nut 86 may be tightened or loosened with respect to the threaded shank 78. When the parts are assembled, the aligned and registering openings 74 through the anterior cushion 72, and 64 in the base plate 58, and the recess 52 in the foot member, define a shaft in which is located the movable pivot joint comprising the aforesaid bifurcated head 76, shank 78, and a large pivot screw 96 which is received in the furcations of the bifurcated head 76, this screw 96 passing through aligned holes in the said furcations of the bifurcated head 76. This pivot screw 96 extends transversely of the ankle assembly as will be clear from the drawings.

The said furcations of the head 76 of this movable pivot joint receive between them a tongue portion 94 of a second pivot member, this tongue 94 having a hole therethrough registering with the holes in the furcations of the said head 76 for mounting the said tongue portion or element on the pivot screw 96, this tongue portion 94 depending from and being integral with a head portion including a bearing sleeve 98 having a bearing opening 100 therethrough which receives the tubular pivot screw 34 that has been referred to above. As has been referred to above, the pivot screw 34 is received in the bore 28 provided therefor which extends into the head plate 20 from the center of the forward surface thereof, and which registers with the opening 100 in the bearing sleeve 98, the pivot screw 34 being disposed in a plane above and at right angles to the aforesaid pivot screw 96.

Therefore, the foot element B pivots longitudinally on the pivot screw 96, it having imparted thereto fore and aft pivotal movements simulating the walking movements of a natural foot. Also, lateral pivotal movements of the foot element B from side to side are accomplished by the movements of the foot element B about this pivot screw 34, such lateral movements corresponding to lateral twisting motions of a natural foot. Additionally, it will be noted that a clearance 102 is provided between the bifurcated head 76 and the inside surfaces of the square hole 26 provided in the head section (or head plate) 20 into which the bearing sleeve 98 is received, so that eccentric or wobbling rotary motions, which may be considered to be composites of the aforesaid longitudinal and lateral pivotal movements, also may be imparted to the foot element B in similitude to such rotary movements in a natural foot.

It is apparent that the moving parts of the ankle joint construction must have smooth and silent movements at all times, and consequently, the present invention contemplates the provision of efficient lubricating instrumentalities for effecting the requisite smooth and silent operations. Such lubricating instrumentalities include a continuous suppy or reservoir of lubricant and means for supplying requisite portions of lubricant from such reservoir under pressure to engaging surfaces of relatively moving or movable parts.

Such lubricating instrumentalities may take variously modified specific adaptations. Thus, for example, the pivot screw 34 may be made tubular by provision of a bore 104, which is threaded internally for a substantial distance as is indicated at 106 for receiving an externally-threaded lubricant-injecting screw plug 108 that is recessed suitably at its forward end, as is indicated at 110 for reception of an operating tool for moving the said lubricant-injecting screw along the threads 106.

The before-mentioned bore 104 in pivot screw 34 communicates with a port 112 that extends through the wall of the screw 34, the said port 112 opening into an annular channel 113 which encloses the screw 34, and also into a duct 114 in the tongue 94 that leads to an annular channel 116 about the pivot screw 96. The said bore 104 in pivot screw 34 receives a supply of fluid lubricant 118, and forms a reservoir for containing a continuous supply of this lubricant, which is introduced into the said bore after removal of the screw plug 108. After placement of the supply of lubricant 118 in the bore, the injection screw plug 108 is inserted and advanced along the threads 106 of the bore 104, such advancement of the lubricant injection screw 108, after engagement thereof with the supply of lubricant, forcing portions of the lubricant from the said supply through port 112 and into channel 113 and thence through duct 114 into channel 116, this action being repeated whenever fresh increments of the lubricant are desired from the reservoir supply thereof in the pivot screw 34. In this manner there is maintained a continuously efficient

lubrication of all moving parts of the construction, lubricant thus forced under pressure into channel 113 lubricating lateral pivotal movements of the foot element B about the pivot screw 34; and lubricant forced through duct 114 into channel 116 around the pivot screw 96 lubricates longitudinal fore and aft pivotal movements of the foot on this pivot screw 96.

In order to further cushion these fore and aft pivotal movements of the foot B, a resilient cushion is provided also for the heel portions of the foot. Such cushion is indicated generally at 120 and it consists of two equal and oppositely directed conical sections 122 and 124 joined together by an intermediate section 126 which is characterized by an annular groove 128 that provides a central area of reduced diameter on which the cushion element can compress in an even manner. As will be seen from the drawings, each conical section 122 and 124 is equal in height, slope, and diameter, and each tapers uniformly from the grooved intermediate section 126 to a planar end 130, one of which seats on the bottom of heel recess 48 in the heel of foot B, the other of which seats against the top of recess 24 of the head plate 20, the latter recess substantially enclosing the top section of the cushion, while the bottom section of the cushion is substantially enclosed by the annular side wall of recess 48 together with that of hole 60 in the base plate 58. It will be observed that there is provided the aforesaid substantial space 68 between the rear portions of the assembly which is maintained by the forward resilient cushion 70 and the rearwardly sloping surface of the base plate 58 that extends from the longitudinal pivot 96 and the heel of the foot, which space is enclosed by the flexible collar 62, which also encloses the forward surface of the resilient cushion 70 and a substantial portion of the head plate 20, the collar 62 extending all the way around the foot and enclosing all connecting and operating elements of the assembly which connects the foot to the head section or plate 20.

In addition to the above, a resilient sole cushion 134 is provided beneath the sole portion of foot B and a resilient heel cushion 136 is provided beneath the heel of the foot. Leather coverings 138 and 140 are provided for these cushions, respectively.

It will be noted in connection with the foregoing embodiment of the improved construction that the threads 30 in the bore 28 of the head plate 20 are located only adjacent to the forward end of the bore, the externally threaded end 32 of the tubular pivot screw 34 being complemental to these threads 30, the lubricant-injection screw 108 meshing with the internal threads 106 in the pivot screw. The threaded head 32 of the pivot screw 34 is provided with a kerf 142 for receiving a screwdriver or similar tool for manipulating the pivot screw.

In the modification of lubricating means shown in Fig. 5 of the accompanying drawings, the head plate 20 is internally threaded as is indicated at 144 through substantially the entire length of the said bore which is designated at 146, in which is positioned a pivot screw 147 having a complementarily-threaded head 148 and an interior tubular recess 150 for holding a reservoir of lubricant. This recess 150 communicates with a feeding port 152 for lubricant, this opening into annular channel 154 surrounding the pivot screw 147. This channel communicates with lubricant duct 155 in pivot bearing 156, the duct 155 conveying lubricant into annular recess 158 surrounding pivot screw 160 which corresponds to pivot screw 96 of the previously described modification. In the showing of Fig. 5, a supply of lubricant 162 is placed directly into the internally threaded bore 144 in the head plate 20 instead of such supply of lubricant being placed in the tubular pivot pin; and also, in accordance with Fig. 5, the lubricant feed screw 164 is inserted in the bore 144 instead of in the tubular pivot pin or bolt.

The pivot pin 147 is provided with an operating kerf 166, and the feed screw 164 has an operating kerf 168 therein, whereby the feed screw 164 may be advanced along the threads 144, forcing lubricant from the supply 162 thereof into the duct 150, thence through feed port 152, annular channel 154, duct 155 and into annular recess 158 for lubricating both the pivot pin 147 and large pivot screw 160.

It will be apparent from the drawings that the structural details of the present ankle joint assembly are subject to many different modifications without departing from the inventive concept. Thus, while Fig. 5 shows a modified lubricating structure from that shown in Figs. 1–4, a modified embodiment of the general assembly is shown in Figs. 6–10.

In this modification, the head plate 170 is a relatively thin plate which is cast with an annular flange 172 which is embedded in reinforcement 174 for firm anchorage of the head section to the lower end of leg A. This reinforcement 174 may be any suitable material, for example, a synthetic plastic material which intimately engages and anchors the flange 172. This flange 172 with its web 176 and head section plate 170 define oppositely directed channels 178, 180, the former being an outer peripheral channel for a purpose to be referred to hereinafter, while the latter is an inner channel that is filled with anchoring plastic reinforcement 174.

The head section plate 170 also is cast with an opening 182 therethrough which is positioned in advance of the vertical axis of the plate and which is enclosed by a flange 184 which is integral with the underside of the plate and which is formed with approximately hemi-spherical aligned bearing lugs 186, between which is received a block or head 188 from which projects a tongue 190 that is received between furcations 192 of bifurcated head 194 of movable pivot bolt 196 that extends through the foot member B as will be referred to hereinafter.

The bearing lugs 186 and the head 188 have horizontally registering holes therethrough for reception of horizontally extending pivot pin 198 which has a threaded head end 200 meshing with threads 202 in the forward end of the hole in forward bearing lug 186. The pivot pin 198 is provided with a threaded bore 204 for receiving lubricant and also a lubricant feed screw 206 having an end socket 208 for receiving a suitable tool for advancing or retracting the feed screw 206 relative to the threaded bore 204.

The inner end portion of the bore 204 is constricted, as is indicated at 210, this constricted portion of the bore delimiting the end of inward movement of the lubricant feed screw 206, and the said constricted end portion of the bore is provided with a lubricant feed port 212 which communicates with an annular channel 214 that encloses the pivot pin for lubrication thereof. The channel 214 communicates with lubricant feed duct 216 in the pivot tongue 190, this duct opening into an annular lubricant-receiving channel 218 which encloses large pivot screw 220 that is received in registering holes in the furcations 192 of bifurcated head 194 of the pivot bolt 196, it being apparent that such holes are in aligned register for receiving this pivot screw 220 which comprises three sections, namely, an enlarged head 222 having a kerf 224 for receiving an operating tool such as a screwdriver, a smooth-surfaced collar 226 and a threaded shank 228, this last section having the smallest diameter, the threads of which mesh with threads in the opening which receives this shank. The pivot pin 198 provides for lateral pivotal movement of the foot while the large pivot screw 220 provides for longitudinal fore and aft pivotal movements of the foot.

The head section plate 170 also is formed adjacent to its heel portion with a recess 230 by elevating a portion of the plate 170 as shown at 232 for forming the top of the recess, which recess is completed by an annular flange 234 which is integral with the under surface of the plate 170.

This recess 230 defines a retaining seat for the top section 236 of a resilient heel cushion 238, the top surface 240 of which is substantially planar for flat engagement with the top 232 of the recess 230. In the present instance, the resilient heel cushion or plug is composed of two unequal sections. The top section 236 of this heel cushion is substantially shorter than the lower section 242 and is substantially cylindrical in contour, whereas the lower section 242 is conically tapered in contour and is retained in recess 244 in the base section or plate 246. The sections 236 and 242 of the heel cushion are defined by a deep annular groove 241 that forms an area of maximum but uniform yielding between the sections of the heel cushion.

The base section or plate 246 is secured in place in the cavity 248 of the foot B by screws 250, the plate 246 being countersunk in the bottom of the cavity 248 and forms a partial bottom surface for such cavity, terminating short of the forward wall of the cavity as is indicated at 251.

The base plate 246 is provided in the instep portion of the foot with a square opening 252 that extends through

the foot for receiving threaded shank 254 of the pivot bolt 196 and also the bifurcated head 194 thereof, this latter defining a substantially square shoulder 255 with the bolt 196.

A bottom plate 256 is provided in the foot member B and extends from the heel of the foot forwardly to substantially the ball portion of the foot, this bottom plate having an opening 257 therethrough which receives the shank 254 of the pivot bolt 196. The plate 256 forms the bottom for the square opening 252 in the aforesaid base plate 246, the opening 257 being substantially smaller that the square opening 252 but concentrically aligned therewith. The said square opening 252 receives the bifurcated head 192 of the pivot bolt, this head having its square shoulder surface 255 seated on a resilient block or washer 282 interposed between the bifurcated head 192 and the bottom plate 256, the end of threaded shank 254 projecting through this bottom plate and receiving a locking washer or nut 258 which is countersunk in opening 259 in a sole plate 266 which extends through the entire foot member in direct engagement with the underside of the aforesaid bottom plate 256, this latter plate being secured by screws 261 penetrating into the wood of the foot member B.

The nut 258 locks the parts of the assembly together and performs additionally other functions which will be described hereinafter. It is operated by a spanner wrench receivable in diametrically oppositely located peripheral notches 260 and a set screw 262 inserted in an appropriate screw hole 264 of an arcuate series thereof provided in the instep portion adjusts the foot member angularly with respect to its mating foot.

A sole plate 266 is provided for the entire foot as aforesaid, this plate and foot member being enclosed in a leather binding 268 which is held in place by folding its edge, as shown at 270, over peripheral flange 272 of the base plate 246, and also, as is indicated by peripheral fold 274, over the periphery of the foot cavity 248, this binding having its fold cemented or otherwise secured to the interior of the cavity 248 adjacent to the peripheral edge thereof. The foot member and lower extremity of the leg are enclosed in a flexible cuff 276, which also encloses the angle joint assembly.

Interposed between the head plate 170 and the base plate 246 and in advance of the resilient heel cushion plug 238 is a thick resilient anterior cushion 278 having a large cavity 280 therein having a bottom 281 provided with a square hole 284. The bifurcated head 192 of the vertically disposed pivot bolt 196 is received in this square hole 284. The side walls of the cavity 280 are substantialy straight and define a clearance between them and the bifurcated head 192 as is true also of the opening 252 in the foot. The bearing lugs 186 and intervening head 188, together with the pivot pin 198, are received in the cavity 280 with an intervening clearance. The leg is provided with a concealing covering 286 simulating a sock or other covering, which is folded in channel 178 and held against the web 176 by means of tightly applied cord wrappings 288.

Comparing the two principal embodiments of the present construction shown in the drawings, reference again may be made to Figs. 1, 2, and 3, as well as to Figs. 4 and 5, which may be regarded as auxiliary views to the construction of Figs. 1, 2, and 3.

From Figs. 1 through 3, it will be seen that the thick head plate 20 is affixed permanently to bottom closure 12 of the leg by the anchor bolt assembly composed of the section 18, threaded shank 14 and lock nut 15 thereon. Also forward and rear permanent attachment is afforded by anterior pins 38 and posterior screw 40, this head plate 20 defining a closure for cavity 44 in the foot member B, the base plate 58 seating on the bottom of this cavity with the round posterior (heel) opening 60 registering with the posterior recess 48 in the bottom of the foot cavity 44. The recesses 48 and 60 diverge upwardly to receive and to conform to the shape of the lower section 124 of the resilient heel cushion 120. Corresponding recess 24 in the head plate 20 receives the top section 122 of this resilient heel cushion 120, these sections 122 and 124 being identical, but opposite, in shape.

The forward or anterior (metatarsal) cushion 70 has a gradual rear taper, its thickest portion being located in what corresponds to the metatarsal portions of a natural foot. The upper surface of this anterior resilient cushion 70 is in engagement throughout its extent with the corresponding area of the bottom surface of the head plate 20, this latter having planar top and bottom surfaces, and is of uniform thickness throughout.

The opening 74 of this anterior cushion registers with recess 52 in the bottom of cavity 46 in the foot member, the bifurcated head 76 of movable pivot joint 78 seating on the bottom of this recess 52 and projecting upwardly through opening 64 in the base plate 58 and into opening 74 in the forward or anterior cushion 70, the pivot screw 96 extending through the furcations of the bifurcated head and being positioned within the opening 74 of the anterior cushion. This pivot screw 96 extends transversely relative to the foot member and provides for longitudinal pivotal movements of the foot (fore and aft pivotal movements) through pivotal rocking of tongue 94 on this pivot screw 96, the bearing head 98 for pivot bolt 34 seating on the radially curved ends of the furcations of the bifurcated pivot head 76 and follows the radial contour of the ends of such furcations during longitudinal pivotal movements of the foot member about the pivot screw 96. Bearing 100 in the bearing head 98 receives the pivot pin 34 which is inserted in the bore 28 extending rearwardly through the head plate 20 from the front surface thereof, this pivot pin 34 being secured in position through intermeshing of head 32 on the head of the pin with internal threads 30 in the forward end of the bore 28. Lateral pivotal movement of the foot member occurs on this pivot pin 34.

It will be seen also that the base plate 58 increases in thickness from the forward surface thereof to its mid-portion which is rearward of opening 64, the plate 58 then decreasing in thickness to its rear surface which abuts against the heel portions of the cavity 44, so that the clearance space 68 between the head plate 20 and the base plate 58 rapidly widens towards the heel of the foot member, there being relative sliding movement between the head plate 20 and collar 62 mounted on the foot member. The cushion 80, seated in recess 52 and engaged by both the base plate 58 and bifurcated head 76 of the pivot bolt 78, absorbs vertically directed impacts during walking, this cushion 80 being continuously under compression.

The pivot screws 96 and 34 are disposed at right angles to each other as aforesaid, with the screw 34 positioned above pivot screw 96. This latter, as has been pointed out above, extends in a direction transversely of the foot member to provide for longitudinal (fore and aft) pivoting of the foot during walking, while the former (that is, pivot screw 34) extends through the head plate 20 in a longitudinal direction, thereby enabling the foot member to pivot laterally from side to side by the bearing 98 turning on this screw 34. It will be seen also from the drawings that there are provided clearances between the bearing 98 and the sides of opening 26 in the head plate 20, and between the bifurcated head 76 and the sides of the opening 64 in the base plate 58. Therefore, there are enabled to be applied to the foot member not only the above-mentioned longitudinal pivotal movements which correspond to normal walking motions of a natural foot, and also side to side (lateral) movements which correspond to similar lateral movements of a natural foot, but the foot member also is enabled to utilize a combination of these motions as is the case with a natural foot, to produce "wobbling" rotary motions which closely simulate corresponding movements of a natural foot.

It is apparent also that to assure smooth and noiseless movements of the foot member there must be an efficient lubrication of the pivots, and pressure lubrication thereof is effected by confining a continuously maintained body of lubricant within the confines of the bore extending into the head plate 20, either by placing the lubricant directly into the bore which has been prepared therefor, as shown in Fig. 5, or by maintaining the body of lubricant within the longitudinally extending pivot pin when the latter is tubular for this purpose, as is indicated in Fig. 4.

There being maintained a continuous supply of lubricant, such may be pressure-injected around the pivots by advancing the lubricant injection screws 108 in Fig. 4 or 164 in Fig. 5 so as to pressure-inject a requisite increment of lubricant into the lubricating channels surrounding both pivot screws, and which are in communication one with the other through the lubricant passage duct provided in the bearing tongue (94 or 156) that is

received between the furcations of the bifurcated head of the pivot bolt.

It will be seen additionally that during walking, as is normally the case, the weight of the wearer is applied to the heel or posterior portions of the foot member, thus causing the rear or heel portions of the head section 20 to be depressed into the collar 62 against the resiliency of the posterior cushion 120 which is compressed under the weight of the wearer. As the wearer's weight becomes shifted forwardly during walking with corresponding longitudinal pivoting of the foot member, the anterior resilient cushion 70 becomes compressed progressively forwardly and the compression on the posterior or heel cushion 120 is released and the latter comes under tension by virtue of the attachment of the heel portion of head plate 20 to the leg closure 12 through screw 40. When the foot member is lifted from the ground during walking, the release of compression on the anterior cushion 70 and expansion thereof and the attendant release of tension on the posterior cushion 120 automatically return the foot member to normal position relative to the leg; and it will be seen readily from the drawings that in all pivotal movements of the foot member, one of these resilient cushions is under compression while the other is under tension, the compressional and tensional forces being applied alternately, resulting in automatic return of the foot member to normal position whenever the weight of the wearer is relieved from the foot member.

Accordingly, it will be seen that the improved ankle joint construction of the present invention enables the foot member to perform all of the motions possible in a natural foot, and that the inherently resilient posterior and anterior cushioning members function in a manner entirely analogous to the posterior and anterior muscles and ligaments of a natural foot which, in the present prosthesis, these resilient cushioning members are designed to replace.

The action of the resilient members 278 and 238 in the modified structural embodiment shown in Figs. 6, 7, and 8 of the accompanying drawings is entirely similar to the action of the cushioning members 70 and 120 and consequently no further explanation is needed. The same applies to the action of the pivot members 198 and 220 of the embodiment of Figs. 6, 7, and 8, and also to the action and operation of the slightly modified lubricating system shown in Fig. 9.

In the embodiment of the construction shown in Figs. 1, 2, and 3, disassembling may be effected by unscrewing washer nut 90 by a spanner wrench engaged in notches 92, this enabling the foot member B to be removed bodily along with the cushion 80 and the anterior and posterior cushions 70 and 120. This provides free access to the top pivot screw or pin 34 (or 147) for requisite advancement of the injection screw 108 or 164 as the case may be for supplying lubricant as needed from the continuously maintained source thereof to the pivot members. Removal of top pivot member 34 will release bearing 98 and pivot bolt 78 for removal from the head plate 20, if desired.

Generally, similar operations afford access to pivot member 198 in the modified construction illustrated in Figs. 6, 7, and 8. That is, by unscrewing washer 258, the foot member B may be removed from its mounting along with resilient cushioning members 278, 238, and 282, this last being retained, however, in the foot member by bottom plate 256. This provides access to the pivot member 198 for enabling requisite manipulation of the lubricant injection screw 206.

It will be observed also that the aligned openings 74 in the anterior cushion 70 and 64 in the base plate 58 (modification of Figs. 1, 2, and 3) and correspondingly, the openings 284 in the anterior cushion 278 and 252 in the foot member (modification of Figs. 6, 7, and 8) actually define a shaft or well for the reception of the movable pivot joints 96 and 220 of these respective modifications, and that the locking washers or nuts 90 and 258, in addition to being the means for maintaining the foot members and ankle joint assembly, constitute means for controlling the amount of movement of the ankle joints and foot members. In this connection, it will be seen that head plates 20 and 170, respectively, are secured rigidly to the leg member, and the joint members 96 and 220 and associated parts are held securely in place by pivot screws 34 or 198. With the forward and heel cushion members in position, the enclosing foot members are positioned bodily in place with the threaded shanks 78 and 254 inserted through holes 54 and 252 and held by the said locking or control nuts 90 or 258. As the said nuts are tightened, the foot members will be drawn increasingly tightly against the anterior resilient cushion 70 or 278, which becomes correspondingly compressed, as well as the resilient heel (posterior) cushions 120 or 238, and the greater will be the force required to move the foot members around the ankle joints and the more limited becomes the amount of such movement. Conversely, the movable parts are loosened for greater movement with attendant release of pressure on the anterior and posterior cushions by loosening the said locking or control nuts. The movements of the ankle joints therefore, are readily adjustable as to their magnitude to the weight of the individual wearer. The actuation of the said nuts is effected by means of a spanner wrench inserted in the opposite peripheral notches provided for this purpose, this wrench being in practice a key with which the wearer is provided and which is of standard size.

In the embodiment of the construction shown in Figs. 1 through 3, the top ankle plate 20 has the pair of symmetrically placed pins 38 on the forward portion of the top surface 22 of the plate, these pins 38 being provided for obtaining the correct amount of "toe in" or "toe out" of the foot element B before the prosthesis is assembled. Thus, "toe out" is an angle away from the body of approximately 15° for correct setting, or according to the "toe in" or "toe out" which the individual may have.

The movable joints 76, 192 of both modifications are secured in the top ankle plate by the pivot screw 34 or 198 which allows the joint to have motion laterally from side to side. The lower part of the movable joint fits into the shaft or well provided therefor in the lower ankle plate 58 or 246, which plate seats in the foot member. The lower part of the movable joints, including the bifurcated head and threaded shank thereof, together with the pivot screw which passes through the bifurcated head of each joint, allows longitudinal forward and backward pivotal movements of the foot members similar to normal walking movements of a natural foot, while the pivot screws mounted in the head plates at right angles to the bifurcated head allow for lateral or side-to-side pivotal movements of the foot members. The combinations of the longitudinal forward and backward movements and the lateral side-to-side movements of the foot members produce an eccentric rotary twisting or wobbling motion of the foot members referred to above.

In both forms of the construction illustrated in Figs. 1 through 3 and Figs. 6 through 8, the entire ankle joint mechanism is enclosed by the recess in the shoe members taken with the head plates which are secured rigidly to the leg and which are recessed to receive the vertically movable or adjustable pivot joint, the heel cushion, and the fixed pivot screw which extends into the head plates at right angles to the vertically adjustable pivot joint. The forward or anterior resilient cushion member which is mounted between the forward portions of the head plates and the base plates in the recess of the foot member and engaged thereby, is apertured suitably to receive the bifurcated head of such joint and the pivot screw which extends therethrough transversely of the foot member and provides for the longitudinal pivotal movement of the foot member about this pivot screw which is held in the tongue projection of the complemental joint member that is fixedly held by the pivot screw that is mounted in the head plate and extends therein in a direction longitudinally of the foot member, that is, at right angles to the pivot screw of the vertically movable joint. In a similar manner, the posterior or heel cushion is retained in a recess in the head plate and in the bottom of the recess of the foot member.

As the adjusting nuts in the bottoms of the foot members are tightened, the foot members are pulled upwardly to compress both the forward and heel cushions, the amount depending upon the tightness of the foot member against the head plate, which tightness is adjusted in accordance with the weight of the wearer. It will be seen that the resilient heel cushion replaces the heel muscles and ligaments of a natural foot, and the anterior

resilient cushion replaces the anterior or forward muscles and ligaments of a nutural foot, and during wearing, the weight of the wearer is applied alternately to the anterior resilient cushion and to the resilient heel cushion in the manner in which the weight of the individual is shifted between the forward and heel portions of the natural foot so that when the wearer's weight is exerted mainly on the forward cushion, it is compressed further, and the heel cushion can expand, and contrarily, application of the wearer's weight principally on the heel cushion compresses the cushion and allows the anterior cushion to expand, the resulting movements of the foot member thereby imitating closely the movements of a natural foot, with elimination of transmission of walking impacts or shocks to the wearer.

From the foregoing description, it will be seen that the present invention provides an improved prosthetic ankle joint which fits all types of prosthetic legs or where an amputee has been provided with a prosthetic shin member and foot therefor for replacement of a natural foot which has been amputated at the ankle, which enables the prosthetic foot to be moved in all directions simulating the movements of a natural foot, and which, like a natural foot, is returned automatically to normal position responsively to completion of its movements. The ankle construction of the present invention can be used interchangeably on a right or left leg, or where there has been a double amputation.

Having thus described my invention, what I claim as new and wish to secure by Letters Patent is:

1. In a prosthetic appliance including a leg member and a foot member, the improvements which comprise an ankle joint structure interconnecting the leg member and the foot member enabling substantially universal pivotal movements of the foot member relative to the leg member, the said ankle joint structure comprising a head plate permanently and rigidly secured to the leg member, a base plate in the foot member and defining the bottom of an open top cavity in the foot member, an adjustable joint extending through the foot member and having a threaded shank extending from the bottom of the foot member and a head portion in the cavity of the foot member, a complemental joint member secured in the said head plate and extending into the head portion of the adjustable joint, a pivot member interconnecting the said head and extending portion of the complemental joint member, the said pivot member extending transversely of the foot member and enabling longitudinal pivotal movements of the foot member similar to movements of a natural foot during walking, a pivot screw mounted in the head plate in a longitudinal direction of the foot member and extending through the complemental joint member for enabling lateral pivotal movements of the foot member, a resilient anterior cushion intermediate forward portions of the head plate and the base plate, a resilient heel cushion retained in the said plate and base plate rearwardly of the foot member, and adjusting means on the threaded shank of the adjustable joint securing the foot member to the leg member under a selected tightness proportional to the weight of a wearer of the prosthetic appliance.

2. In a prosthetic appliance including a leg member and a foot member, the foot member being separable from the leg member, the improvements which comprise an ankle joint structure pivotally interconnecting the foot member to the leg member and comprising an ankle joint assembly mounted in the foot member and including a head plate and a base plate, means rigidly securing the head plate to the leg member, the base plate being secured to the bottom of an open top cavity in the foot member, a vertically adjustable ankle joint assembly mounted in the foot member and including a head portion, a shank portion extending through the foot member to the bottom thereof, a complemental joint member having an upper portion mounted in the head plate and a tongue portion extending into the head portion of the adjustable joint assembly and a pivot member interconnecting the said head portion and tongue portion and extending transversely of the foot member providing longitudinal pivotal movements of the foot member relative to the leg member simulating walking movements of a natural foot, a second pivot member mounted in the head plate and extending through the upper portion of the complemental joint member enabling lateral side-to-side pivotal movements of the foot member, a forward resilient cushion compressionally retained between forward portions of the head plate and base plate and simulating forward muscles and ligaments of a natural foot, a resilient heel cushion also retained between rear portions of the head plate and heel portions of the foot member and simulating heel muscles and ligaments of a natural foot, the forward cushion having an opening therethrough for receiving the head portion of the vertically adjustable ankle joint assembly with a clearance thereabout for enabling eccentric rotary pivotal movement of the foot member, the forward cushion and heel cushion being alternately relaxed and compressed responsively to shifting of a wearer's weight between forward and heel portions of the foot member, and means on the shank portion of the adjustable joint assembly for controlling amplitudes of pivotal movements of the foot member in accordance with the weight of the wearer.

3. In a prosthetic appliance including a leg member and a foot member separably connected thereto, the improvements which comprise an ankle joint structure intermediate the said members and pivotally interconnecting them together, the foot member having an extensive open top cavity therein receiving and enclosing principal elements of the ankle joint structure, the said ankle joint structure comprising a vertically disposed adjustable ankle joint having a head and a shank, the said head being positioned in the cavity, a complemental fixedly mounted joint member extending into the said head, pivot means pivotally interconnecting the head and complemental member and extending transversely relatively to the foot member, and enabling the foot member to pivot in a longitudinal fore and aft direction with movements simulating walking movements of a natural foot, a resilient yieldable forward cushion in the cavity adapted to be yieldingly compressed during forward application of a wearer's weight thereon during walking, a rear yieldable resilient cushion also mounted in the cavity adjacent to heel portions thereof adapted to be yieldingly compressed during rearward application thereto of the wearer's weight during walking, the said cushions being alternately compressed and expanded as the wearer's weight is shifted from one to the other during walking, each cushion returning the foot member to normal position responsively to release of the wearer's weight therefrom, the forward cushion member simulating in its action natural muscles and ligaments in forward portions of a natural foot and the rear cushion simulating in its action natural heel muscles and ligaments of a natural foot, and means on the shank of the ankle joint and engaging the foot member for movably adjusting the latter relative to the ankle joint and cushions for initially compressing the latter equally against the weight of the wearer when the said weight is applied equally to the cushions and for controllably limiting amplitudes of movement of the foot member in accordance with the weight of the wearer when uniformly applied to the said cushions.

4. In a prosthetic appliance including a leg member and a foot member separably connected thereto, the improvements which comprise an ankle joint structure intermediate the said members and pivotally interconnecting them together, the foot member having an extensive open top cavity therein receiving and enclosing principal elements of the ankle joint structure, the said ankle joint structure comprising a vertically disposed adjustable ankle joint having a head in the cavity and a threaded shank extending from the head through the foot member and extending from the bottom thereof, a head plate rigidly secured to the leg member, a base plate defining the bottom surface of the cavity and rigidly secured to the foot member in the bottom of the cavity, a forward resilient and elastic cushion member intermediate the head plate and the base plate, and enclosing the head of the adjustable ankle joint, a complemental joint member for the adjustable ankle joint having a head portion mounted in the said head plate and a tongue portion depending therefrom and engaging with the head of the adjustable ankle joint, pivot means interconnecting the tongue portion of the complemental joint member and the head of the adjustable ankle joint and extending transversely relative to the foot member, a pivot member secured in the head plate and extending longitudinally of the foot member at right angles to the adjustable ankle joint and to the complemental joint member and extending through the head portion of the lat-

ter for enabling lateral pivotal movements of the foot member, the transversely extending pivot means in the head of the adjustable ankle joint and complemental joint member enabling longitudinal pivotal movements of the foot members, a resilient elastic heel cushion member in the cavity of the foot member and retained between the head plate and base plate, the forward cushion member and the heel cushion member becoming alternately expanded and compressed during shifting of a wearer's weight while walking, and adjusting means on the shank of the adjustable ankle joint for selectively tightening and loosening the foot member relative to the forward and heel cushion members, the said cushion members simulating forward and heel muscles and ligaments of a natural foot and returning the foot member to normal position following pivotal movements thereof in any direction.

5. The construction as claimed in claim 4 wherein the pivot member in the head plate is tubular for receiving and maintaining a supply of lubricant in the pivot member, a lubricant-receiving channel in the head portion of the complemental joint member surrounding the said pivot member, the latter being provided with a port communicating with the channel and with the supply of lubricant in the pivot member, a second lubricant-receiving channel being provided in the tongue portion of the complemental joint member around the pivot means interconnecting the said tongue portion and head of the adjustable ankle joint, a lubricant-delivery passage in the said tongue portion interconnecting the channel in the head portion of the complemental joint member with the second channel, and lubricant-injecting pressure means in the head plate acting on the supply of lubricant in the pivot member in the head plate for supplying lubricant from the said pivot member into the lubricant-receiving channels.

No references cited.

O. A. INGEBRIGTSEN.
ARTIFICIAL ANKLE JOINT.
APPLICATION FILED FEB. 11, 1919.

1,334,861. Patented Mar. 23, 1920.

Fig.1.

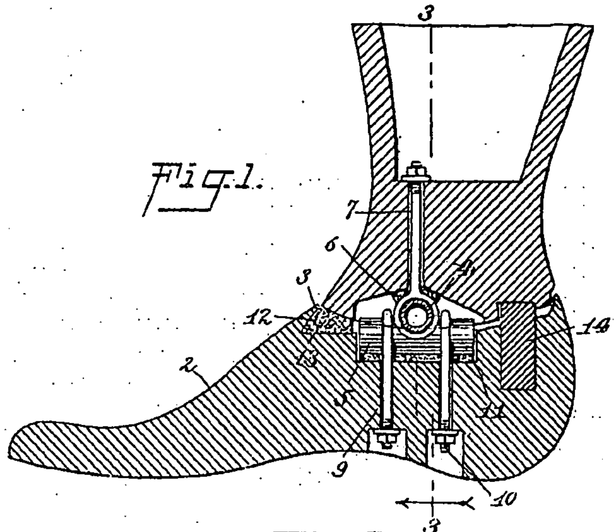


Fig.2.

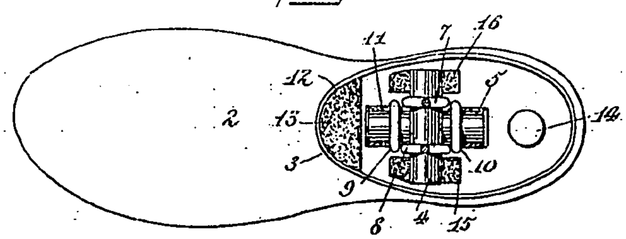


Fig.3.

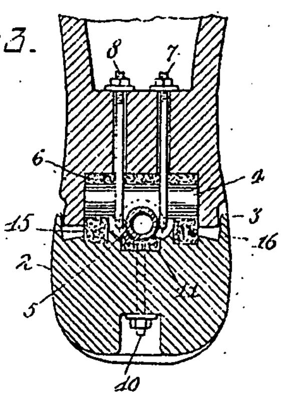
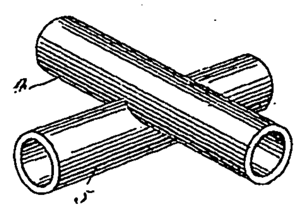


Fig.4.



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ARTIFICIAL ANKLE-JOINT.

1,334,861. Specification of Letters Patent. Patented Mar. 23, 1920.

Application filed February 11, 1919. Serial No. 276,269.

To all whom it may concern:

Be it known that I, OLE A. INGEBRIGTSEN, a citizen of the United States, and a resident of the city of New York, borough of Manhattan, in the county and State of New York, have invented a new and Improved Artificial Ankle-Joint, of which the following is a full, clear, and exact description.

This invention relates to artificial limbs and has for an object the provision of an improved ankle joint which will permit an independent back and forth swinging movement in a vertical plane of the foot.

In the accompanying drawing:

Figure 1 is a longitudinal vertical section through a foot and ankle of an artificial limb disclosing an embodiment of the invention.

Fig. 2 is a top plan view of the foot and ankle structure, certain parts being broken away.

Fig. 3 is a section through Fig. 1 on line 3—3.

Fig. 4 is a perspective view on an enlarged scale of the journal members of the joint.

Referring to the accompanying drawing by numerals, 1 indicates the leg structure which is substantially of the usual form except the lower part which fits into the foot 2. The foot 2 is provided with an encircling or annular flange 3 in which the lower part of the leg 1 moves forwardly and rearwardly pivotally and also sidewise pivotally. The upper part of the foot 2 is cut away for the various parts hereinafter fully described, while the lower part of the leg 1 is also cut away for accommodating certain parts. The principle or central part of the ankle joint are the journal members 4 and 5, which are welded or otherwise rigidly secured together, and which are preferably tubular so as to present an ample exterior bearing surface and yet not present an unnecessarily heavy structure. These journal members are arranged at right angles to each other and the upper journal member 4 acts as the journal member for the foot 2 when swinging fore and aft, while the lower journal member 5 acts as the journal member when the foot 2 is swinging laterally. Journal member 4 is pressed tightly against anti-friction member 6 which may be of leather or other suitable material, said anti-friction member 6 pressing against leg 1 by reason of the fact that the anchor bolts 7 and 8 encircle the bar 4 as shown in Fig. 1 and extend upwardly to a given point where they are clamped in place by suitable nuts. It is desired to provide a reasonably free swinging movement in two directions at right angles to each other, but it is not desirable to provide any loose motion. The lower bar 5 accommodates the eyes of the bolts 9 and 10, which bolts extend through part of the foot 2 and are held in position by suitable nuts which cause the bar 5 to press against the friction member 11, said friction being made of leather or other suitable material. A notch 12 is provided at the front of the bar 5 in which felt, or a very yielding rubber member 13 is placed, which is, of course, compressed when the leg 1 is swung forwardly. A comparatively long rubber bumper 14 is arranged in a suitable aperture in foot 2 and continually presses against the leg 1. When swinging the leg 1 rearwardly at the top part the rubber bumper 14 is compressed and takes up the strain. The side movement of the foot 2 is taken up by the rubber cushioning members 15 and 16 arranged beneath each end of the journal member 4, said cushioning members being fitted into suitable notches in the foot 2. By this construction and arrangement the foot is given a more natural action as it will automatically swing to one side in case a small object is stepped on near one edge. This is also true of the front and back movement of the foot by reason of the cushions 13 and 14. These cushioning members, of course, limit the amount of movement and also resist such movement, the resistance increasing with the degree of movement until the movement stops.

What I claim is:

1. An artificial ankle comprising a pair of crossed journal members rigidly secured together, means for pivotally connecting one journal member to the leg, means for pivotally connecting the opposite journal member to the foot whereby the foot may swing laterally and in a direction at right angles to the lateral swinging movement, cushioning members arc-shaped in cross section arranged between said journal members and the ankle and foot, and resilient bumpers arranged in front and rear of said journal members and also on each side thereof for limiting the swinging movement of the foot.

2. An artificial limb comprising the combination with a leg and foot and a joint swingable in two directions at right angles

to each other consisting of a pair of connected cylindrical members crossing each other centrally at right angles, a pair of members attached to the leg having spaced circular bearings surrounding one of said cylindrical members, and a similar pair of members attached to the foot having spaced circular bearings surrounding the other of said cylindrical members.

3. In a cordless artificial ankle joint the combination with a leg and foot of a cross shaped journal member having arms extending at right angles to each other, a pair of spaced eyebolts loosely fitting over one of said journal members and connected with said leg, a second pair of eyebolts journaled on the other of said members connected with said foot, an arc-shaped anti-friction member arranged below said last mentioned journal member, an arc-shaped anti-friction member arranged above the first mentioned journal member, a pair of rubber bumpers mounted in said foot and continually pressing against the opposite ends of said first mentioned journal member, a cushioning member arranged at the front of said cross shaped journal members, and a second cushioning member arranged at the rear of said cross-shaped journal members, said cushioning members being carried by said foot and pressing against said leg.

OLE A. INGEBRIGTSEN.